VENTILATION AND HEATING.

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BY

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PREFACE.

IN preparing this volume my object has been to produce a book which will not only be useful to students of Architecture and Engineering, and be convenient for reference by those engaged in the practice of these professions, but which can also be understood by non-professional men who may be interested in the important subjects of which it treats; and hence technical expressions have been avoided as much as possible, and only the simplest formulæ have been employed. It includes all that is practically important of my book on the Principles of Ventilation and Heating, the last edition of which appeared in 1889; but it is substantially a new work, with numerous illustrations of recent practice. For many of these I am indebted to THE ENGINEERING RECORD, in which the descriptions first appeared.

I am also indebted to Dr. A. C. Abbott for much valuable assistance in its preparation, and to the architects and heating engineers who have furnished me with plans and information, and whose names are mentioned in connection with the descriptions of the several buildings, etc., referred to in the text.

JOHN S. BILLINGS.

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CHAPTER I.

INTRODUCTION. UTILITY OF VENTILATION.

VENTILATION, in the sense in which the word is used in this book, is the continuous, and more or less systematic, changing or renewal of the air in a room or other closed space. In simple aeration of a room the air is changed but once, or at intervals, while ventilation implies that the change is constantly going on by the passing out of a portion of the enclosed air and the entrance of other air to take its place. It is employed and provided for in order to remove substances which become diffused or suspended in the air while it is in the enclosure, to replace the oxygen which has been consumed therein, and in some cases to effect a change of temperature.

While it may be required in some cases chiefly, or exclusively, to remove watery vapor, as in the drying rooms of a factory, or to keep an uninhabited room free from dampness, or to remove offensive or dangerous gases or foul odors generated by either natural or manufacturing processes, it is most usually employed to dilute and remove the products of exhalation and respiration of living animals, especially of man, and the products of combustion due to heating and illuminating apparatus, and to prevent the temperature of a room from rising above the degree which is requisite to secure comfort and health.

It involves the introduction of the comparatively pure external air in continuous currents, the diffusion of this air throughout the room, and the constant removal of a corresponding volume of the air which has become contaminated by vapors, gases, particulate matters or odors, or which has had its temperature raised within the apartment.

In studying the subject of ventilation, therefore, we have to consider the chemical and physical qualities of the air, the various sources of the changes in its composition which necessitate its renewal, the forces which are available to cause its motion in the direction best suited for the purpose, and the arrangement of openings, ducts, flues, shafts, etc. which are best adapted to secure the entrance, diffusion and exit of the quantity of air required.

When the quantity of air to be supplied has been determined, the general principles which should govern the arrangements in a room or building to secure the satisfactory introduction and distribution of this air are comparatively simple, but their practical application requires a special study of the circumstances of each individual building to secure the best results.

The great majority of human habitations in cold climates have no special provisions for ventilation during that part of the year in which artificial heat is required, and even in the majority of large and costly public buildings such as churches, opera houses, State capitols, court rooms, assembly halls, school houses and hospitals, in which, of late years at least, it is usual to introduce some openings and flues especially destined for the entrance and exit of air, it cannot truthfully be said that satisfactory ventilation has been secured.

There are several causes for this state of things, the most important being ignorance of the utility of fresh pure air for the preservation and improvement of health, and a consequent want of demand for the means of securing a constant supply of this important article. Perhaps instead of "ignorance," it would be better to say "want of appreciation," for most people will admit that ventilation is a good and desirable thing, although it would not occur to them in renting a house to examine as to what means of ventilation of the living rooms are present or available, nor would they think of considering the air supply in selecting a school for their children. The evil effects of the continuous inhalation of impure air are not such in most cases as to attract the notice of men unless the impurity is very considerable, or the conditions of the temperature and moisture are such as to produce evident discomfort at the time. The injury inflicted on the animal mechanism by breathing air deficient in oxygen and contaminated with animal exhalations is not perceptible until after a considerable period of time, and is then usually attributed to other causes, and it has only been by careful and long continued observation of the effects of insufficient ventilation upon bodies of men subjected to it, and by comparison of statistics covering considerable periods of time, that the deleterious results of breathing foul air have been demonstrated. This proof has been obtained from comparing the statistics of the sickness and deaths occurring during a series of years among men in well ventilated and in unventilated barracks, ships and prisons; among cavalry horses in well or ill ventilated stables, and among monkeys and other wild animals when shut up with a defective air supply.

The diseases which are especially produced or aggravated by defective ventilation are those which affect the respiratory tract, including chronic inflammatory affections of the throat and lungs, and especially phthisis. With regard to this last disease there is abundant evidence that it causes a much larger proportion of deaths among men and animals confined in ill ventilated rooms and compelled to breath air contaminated with organic products thrown off by the lungs and skin, than it does among those living in all other respects under similar conditions, but having a constant and abundant supply of fresh air.

The discovery that phthisis is due to the growth and development in the body of a specific micro-organism, the *bacillus tuberculosis*, does not at all invalidate this evidence ; on the contrary it strengthens it ; in part because the probabilities of inhaling the specific disease germ are evidently greater where a number of men or animals are repeatedly breathing air contaminated by the dust of dried sputa or other excretions of their companions, if any one of these is affected by the disease; in part because the inhaling of air loaded with dead or dying organic matter produces changes in the lungs which have apparently the effect of diminishing the power of the normal tissues to destroy the life of disease-producing organisms that may gain access to them. From evidence at hand we must admit the existence of such power on the part of normal tissues and its diminution in, or absence from those that are abnormal. The demonstration by Cornet (Zeitschrift für Hygiene, 1889, Bd. V, s 191) that the dust of apartments occupied by tuberculous individuals frequently contains the bacillus of tuberculosis, justifies us in assuming that in the course of the lives of many of us who are in health and live under proper sanitary surroundings, the organism has been inhaled into the lungs, but has been prevented from playing its pathogenic rôle because of the resistance offered by the healthy lung tissue. But in the abnormal tissues this vital resistance is diminished, or, in some cases, apparently lost, and from analogy we know that this is just the condition in which all kinds of infection most readily occur. It is just this condition of lowered vitality that is found in the bodies of those constantly exposed to the deleterious influences of the polluted air of over-crowded, badly ventilated and otherwise unsanitary apartments.

Statistics showing the excessive prevalence of phthisis in ill ventilated rooms will be found in the published reports of the English, French and German armies, in the reports of the English navy, and in the statistical reports of prisons in this country and in Europe ; and the intimate connection between an excessive death rate from these

affections, whether in man or animals, and defective air supply is now so generally admitted that it is unnecessary to repeat the figures here. The liability to spread by contagion or infection of certain specific fevers, and notably of typhus fever, is greatly increased by insufficient ventilation.

The desirability of provisions for ventilation does not, however, depend upon its being a means for the prevention of consumption, or typhus, or other specific diseases. It comes under the general head of the desirability of cleanliness. Most civilized men and women are unwilling to put on underclothing that has just been taken off by another person, or to put into their mouths articles of food or drink that have recently been in other peoples mouths, but they take, without hesitation, into their lungs air that has just come from other people's mouths and lungs, or from close contact with their soiled clothing or bodies.

In many cases it is difficult, or impossible, to separate the effects of impure air from those of insufficient or improper food, or clothing, or from those of occupation; as for instance, in considering the excessive mortality in tenement houses or in densely populated districts, but if we consider the importance of respiration to life, the immense surface which the air passages and air cells present for the lodgment of particles brought into them by the inspired air, and the favorable conditions as regards moisture and temperature which exist in them for the growth and development of micro-organisms, provided these meet with suitable food in the shape of dead or non-resistant organic matter, we can readily see that the purity of the air breathed, and the constant and prompt removal of the excretions borne out with it, must have much to do with the health and energy of the individual.

It is, therefore, well worth while for every man to understand that abundance of fresh air is not merely theoretically a good thing which is to be accepted, if it comes in his way, but that it is a necessity for the preservation of health and happiness, and that it is worth taking special pains to secure. It is also important that those who form and direct public opinion on this subject—physicians, architects, engineers, clergymen, teachers, school trustees, and legislators, should give more attention to this subject than most of them have heretofore done, and should look to it that the buildings which they plan, erect or manage, and especially those in which numbers of men, women or children are to be brought together, are so constructed and arranged that no one shall poison himself or others by the air which he expires.

I do not mean by this that every professional man should aim to be an expert on plans and specifications for ventilation, nor that he should rely on his own judgment as to the best way to secure it, but that he should insist on having it provided for, and should see that skilled advice on the subject is obtained for all buildings in which he is interested.

The difficulties which architects and engineers find to be most prominent when they attempt to arrange a system of ventilation for a given building, mine, or other locality, are, first, the want of a definite generally recognized standard as to amount of air required; and second, the extra cost of construction and maintenance which is involved in supplying, heating, and distributing this air.

The standards of satisfactory ventilation proposed by sanitarians are not as yet accepted in engineering text books, the authors of which seem disposed to think that much smaller amounts of fresh air than those proposed by Pettenkofer, Parkes and De Chaumont, are sufficient. So long as the question as to whether a given room or building is properly and sufficiently ventilated is to be decided by opinions based on personal sensations only and not upon the results of weight and measure of the constituents and temperature of the air which will be independent of personal equations, so long will it be impossible to obtain an authoritative and reliable answer. Upon the standard for air supply adopted depends, to a considerable extent, the expense of the means required to secure it.

If the question of expense could be entirely set aside ventilation would become a comparatively simple matter, for the resources of modern engineering are ample to produce a given standard of purity of the air in almost any building that can be constructed; but to secure good ventilation in cold climates during the winter is expensive as to the mode of construction of the building itself, the apparatus required for the purpose, and as to its maintenance after the necessary conditions have been provided.

Among the first questions which the architect has to solve for each building which he plans or constructs in order to secure good ventilation are the following—viz.:

First.—How much money shall be allowed to secure ventilation in this case?

Second.—Which of several methods should be employed to effect this, taking into consideration the character and location of the building and the amount of funds available?

The answers to these two problems will seldom, or never, be the same for any two buildings having different owners, and this is one

reason why it is impossible to lay down simple and universal formulas to secure satisfactory heating and ventilation of a large building.

When a gentleman comes to an architect for a plan for a dwelling house, or a board of trustees or directors ask for plans for a school or a hospital, it is not to be supposed that the applicants, while giving general data as to location, dimensions and proposed cost, will have any definite ideas as to how much of this cost is to be devoted to ventilation. It is an important part of the business of an architect to decide this, and to be careful from the very beginning that, even in the first rough sketch plans, as satisfactory arrangements for ventilation are included as the nature of the case will permit. It is also the business of the architect to see that after numerous additions and changes to these sketch plans have been made at the suggestion of various friends and advisers, and the cost has thus been increased above what was intended, the prospective builder or builders do not, in a spasm of economy and retrenchment which may attack them, make a reduction in some point which will affect the ventilation, rather than cut off some of the merely ornamental and comparatively useless decorative work of the exterior.

The connection of the heating of a house with its ventilation is, as we shall show hereafter, inseparable; nevertheless many persons will cheerfully expend from $15,000 to $20,000 in building a dwelling house for themselves in which from $3,000 to $5,000 shall be devoted to ornamental stone work and cornices, who would not think of spending from $1,000 to $1,500 for the necessary hot water or low pressure steam apparatus to keep this same house thoroughly and comfortably warm and well ventilated. If, however, at the very commencement, the desirability of providing for constant ventilation is pointed out by the architect, as he should do in his capacity as expert professional adviser, it will usually be found that his clients will accept his advice just as they will that relating to the proper arrangement of the drains and plumbing work, and by taking this course the architect will find his clients much better satisfied with their houses and with himself than if he defers to their ignorance in these matters. But, however much the architect may be inclined to let the owners have their own way in planning their own residences, when it comes to public buildings such as schools, hospitals, etc., it is his duty not only to advise but to insist upon including proper arrangements for heating, ventilation, drainage and plumbing. If it is his misfortune to have to deal on such matters with ignorant committee men who, with a limited appropriation for the purpose, persist in omitting, for the sake of cheapness,

some of those points in construction which are essential for keeping the building in proper sanitary condition, it is his duty as a skilled professional man to decline to have anything to do with the matter rather than suffer himself to be used as a tool to execute work which he knows will be dangerous to the health and life of his fellow citizens, or of their children.

In most cold climates it is impossible to have at the same time good ventilation, sufficient heating, and cheapness in construction and in the cost of the fuel required during cold weather, to secure comfortable warmth. One reason why the comparative expensiveness of good ventilation is not so well recognized in the United States as it should be, is that much of the literature on the subject has heretofore been furnished by English authors who write with reference to the climate of England. This climate is very different from our own, being much more uniform, and having a much higher average proportion of moisture in the air, which permits of the use of lower temperatures in warming than are acceptable here. In the United States rooms must be kept at a temperature of from 68° to 70° F., to insure the comfort of the occupants and to prevent complaints, while in England 60° F., seems to be the recognized standard.

Open fireplaces and grates can therefore be used there more extensively than here, and in arranging apparatus for heating by indirect radiation, it is necessary to provide more heating surface than is called for by the specifications of English engineers. This is a fact which must be constantly borne in mind in reading the books of Edwards, Hood, or other English writers on this subject, and it will be found well presented and strongly insisted on in a paper by Mr. Robert Briggs, in the January and February numbers of the *Journal of the Franklin Institute* for 1878, entitled, "On the Relation of Moisture in the Air to Health and Comfort."

How may we define "good ventilation," or know whether it has been secured in any given building? In the great majority of cases it includes the idea of a thorough mixing of pure air with impure air, in order that the latter may be diluted to a certain standard.

Perfect ventilation can be said to have been secured in an inhabited room only when any and every person in that room takes into his lungs at each respiration air of the same composition as that surrounding the building, and no part of which has recently been in his own lungs or of those of his neighbors, or which consists of products of combustion generated in the building, while at the same time he feels no currents or draughts of air, and is perfectly comfortable as regards temperature,

being neither too hot nor too cold. Very rarely, indeed, can such perfect ventilation be secured if the number of persons in the room exceeds two or three ; in fact, few attempts have been made in this direction. One of these was in the house of the late Mr. Thomas Winans, of Baltimore, where the floors were perforated uniformly all over the room, as was done by Dr. Reid for the British House of Commons, thus making the floor a gigantic register or grating through which the fresh incoming air, having been previously warmed and moistened in mixing chambers below, is to stream steadily upward at a uniform velocity sufficient to remove all the products of respiration or of combustion as rapidly as formed. It requires even more than this to secure the perfect comfort as regards temperature above alluded to, but this will be explained when we come to speak of the heating and ventilation of large assembly halls. The amount of air required to secure this perfect ventilation is very great. Take, for instance, a room 12 feet square, and suppose that the air in it is to move uniformly upward at the rate of 6 inches per second. This is equivalent to an air supply of 72 feet per second. Theoretically, it is true that, if the air moves regularly and steadily upward at all points in the room at the rate of even 1 inch per second it might be sufficient—but practically, at least six times this velocity is required to overcome disturbances caused by opening doors, the movement of persons, etc.

Probably this statement of air supply required gives no definite idea as to its cost, and it may be more fully understood by considering that it would require at least thirty times as much coal to heat a room thus supplied as would be used for heating a room of the same size having only the ordinary heating and ventilating arrangements.

What would be considered by all sanitarians as good ventilation would not require nearly so much air as this. Good, ordinary ventilation is presumed to be secured by keeping the vitiated air constantly diluted to a certain standard. It does not attempt to maintain in a building or room air as pure as that outside, but only air which shall contain but a certain proportion of impurity—for all the air with which our ventilating appliances are to deal will contain impurities. Some of these impurities are more dangerous than others, and are less affected by this process of dilution. Offensive or poisonous gases of all kinds, such as sulphuretted hydrogen or carbonic oxide, can be diluted by fresh air, just as solutions of arsenic or strychnine can be by pure water, until a mouthful of such diluted air or fluid is neither specially hurtful or unpleasant.

The most dangerous impurity in some air, such as that contained in a hospital ward for contagious diseases, is often not gaseous, has no very marked or unpleasant odor, and cannot be detected by ordinary means of chemical analysis. It consists of minute living organisms which have the power of producing disease when they gain access to the human body under favorable circumstances. Many of these organisms, known as bacteria, have been proven to be the cause of certain specific inflammations and other diseases. The process of diluting by ventilation the air of a room which contains them does not dilute the individual bacterium or spore, and its effect in removing them from the apartment is much less than its effect upon diffused gases or vapors. Most of them are of greater specific gravity than the air, especially when adhering to particles of dust, and hence their tendency is to remain wherever dust can settle, and to be diffused by whatever causes the diffusion of dust in the air, such as sweeping, dusting, movements of persons, or strong air currents.

It is, therefore, evident that the prevention of the entrance of the dangerous forms of micro-organisms into a building where it is possible to do so is a matter of special importance, since it is very difficult to dispose of them by ventilation alone when they have once gained entrance, and hence ventilation is no efficient substitute for proper plumbing, and the avoidance of collections of decaying organic matter within the house.

In the great majority of buildings the ventilation may be planned and arranged with reference only to the ordinary impurities of air in inhabited rooms, and to the maintenance of an agreeable temperature.

It should be remembered, also, that even in the northern part of the United States and in Canada, little or no heat is required for over half of the year, and that buildings can be planned so as to secure good ventilation during the warmer months with little or no extra expense, provided that the matter has been duly considered in the beginning, and not taken up as an afterthought when nearly every detail of construction has been decided upon.

CHAPTER II.

HISTORY AND LITERATURE OF VENTILATION.

THE necessity which exists in certain mines for arrangements to ensure a sufficient supply of fresh air in the deeper shafts and galleries to dilute and expel the gases which would otherwise accumulate and form explosive mixtures, or interfere with respiration and make dim or extinguish the miners' lamps, was probably what first gave rise to plans for ventilation without regard to either heating or to cooling buildings by means of air currents.

The earliest description of apparatus or special methods employed for this purpose is given in the treatise of George Agricola, published in 1546, and entitled "De re metallica," in which the methods used in the mines of Bohemia and Saxony are briefly indicated. These included the use of fire to create an upward current in certain shafts; of a sort of large bellows with which air could be pumped into specially foul and dangerous pits or tunnels, and of rotating fan wheels to ensure a current in an horizontal gallery.

Long before this date, physicians had observed and commented upon the need for the renewal of air to support healthy human life, and had especially directed that this should be secured in the room of a sick person by means of perflation, or, as Celsus suggests, by the use of a small fire; and the use of wind conductors or *mulgufs*, as they are called in Egypt, to secure cold currents of air throughout the house for the sake of coolness, is of very ancient date.

Special openings in the ceilings or roofs were provided in the ancient Roman Baths for the purpose of giving exit to hot air and thus regulating the temperature, and in the Hall of the Baths of the Alhambra at Granada, constructed in the thirteenth century, short, funnel-shaped, glazed tubes are inserted in the roof for purposes of ventilation.

Practically, however, the history of ventilation begins with the attempts at ventilating the Houses of Parliament in London in 1660 by the architect, Sir Christopher Wren; and it has been truly said that, as almost every device has been tried in these halls at one time or

other, the history of these attempts would be almost equivalent to a history of the art of ventilation in its entirety. Sir Christopher's plan was to cut a large square hole in each corner of the ceiling of the House, over each of which holes he placed a short funnel-shaped tube leading into the room above, which funnels could be opened and closed by means of valves. As there were apparently no special provisions for fresh air supply, this scheme produced a sort of circulation, bringing down the cold air from beneath the roof, and giving rise to great complaints of draughts. This led to the calling upon Dr. J. T. Desaguliers to remedy the difficulties, and thus induced this distinguished physicist and mechanician to devote special study to the mechanical problems connected with ventilation.

Dr. Desaguliers was of French origin, having been born in New Rochelle in 1683, and taken by his father to England on the revocation of the Edict of Nantes in 1685. He became a lecturer on experimental philosophy in Oxford in 1710, and in 1714 was made a Fellow of the Royal Society, to which he presented a number of communications in succeeding years, and is well known by his "Course of Experimental Philosophy," which passed through several editions, and in which he gives a modest and rather humorous account of his adventures in trying to improve the ventilation of the House.

The physics of air and the effects of heat were an essential part of his course of instruction; but he had been led to give special attention to the heating and ventilation of houses by a little book by one N. G., published in Paris in 1713, and entitled, "La Mechanique du Feu." In a subsequent edition the author gave his name in full as Nicholas Gauger. In a work entitled, "On the History and Art of Warming and Ventilating Buildings . . . by Walter Bernan," published in two volumes in London in 1845, the authorship of this work by N. G. is attributed to the celebrated Cardinal de Polignac, and this statement has been accepted by many subsequent writers. It may be noted, by the way, that the name "Walter Bernan" appears to have been merely a *nom de plume*, and that the book—which is a valuable one for reference—was really written by Mr. Robert Meikleham, C. E. (See Edwards [F.] on the Ventilation of Dwelling Houses, etc., 8vo., Lond., 1868, p. 2.)

Nicholas Gauger was, however, a very real personage, and, as Mr. Charles Tomlinson has pointed out, was really the author of the book attributed to him. He was a student of experimental philosophy, and his book is a remarkable one, containing, as it does, descriptions of the true principles of some of the best of modern fireplaces, especially

those which are designed to introduce fresh warm air into the room which is to be heated. Dr. Desaguliers translated this work into English, and published it in London in 1715, under the title of "Fires Improved; or, A New Method of Building Chimnies so as to Prevent Their Smoking, in Which a Small Fire Shall Warm a Room Much Better than a Large One Made the Common Way." A second edition of this translation, with an appendix, was published in 1736.

The ideas contained in Gauger's treatise were not all original with him, for the rules for properly proportioning the dimensions of a fireplace and of its chimney to prevent smoking had been stated by a French architect and physician, M. Louis Savot, so early as 1624; but Gauger treats his subject from a scientific as well as a practical point of view, describing experiments to prove that air is heated, not by radiation but by contact with warm surfaces; that warm air rises above that which is cooler, and that currents may thus be produced; and then proceeds to describe and figure fireplaces and grates intended to heat an incoming current of air, by which means, he says, "You may be able to kindle a fire speedily, to warm yourself at the same time on all sides without scorching, to breathe a pure air always fresh, to be never annoyed with smoke in one's apartment, nor have any moisture therein." He points out that the horizontal section of the fireplace should be on the lines of the parabola, in order that the greatest number of rays of heat may be reflected out into the room; provides for the heating of air by conduction from the back, and states that by the fireplace air may be either admitted from the room itself or from the outside; and describes a form of paper pendulum to be used to show the relative velocity of the incoming air in order to determine the amount of air which is admitted, his estimate being that the contents of a room of 2,000 cubic feet should be changed in about a quarter of an hour. He says: "There is indeed an inconveniency, which is, that warm air entering continually will at last make the room too hot; but this is easily remedied by stopping up the hole where the hot air comes in. But then, as there would no longer be a circulation of fresh air, it is better to have a direct communication with the external air near the place where it comes out after it is heated in the hollows! Thus you may sometimes have hot, and sometimes cold, and sometimes temperate air, in what proportion you please, by opening sometimes one hole, sometimes the other, and sometimes both." And again: "To be soon and agreeably warmed by external air brought into a room after the above mentioned manner is not the only or the greatest advantage reaped by our new invention, for as well the incon-

veniences of a great fire as that of extreme cold are removed. The larger particles of the fuel darted out against us, when we have too large a fire, or when we are too near the chimney, burn and dry up the lungs, and ruin the eyes, as may be perceived by their pain and redness; spoil the delicate skin of the ladies, hurt the eyelids and destroy the finest complexions; all which evils are prevented by the use of the new chimneys. As for sick people, they may be looked upon as absolutely necessary; for the corrupted breath of patients, the ill humors which go out of their bodies by transpiration, particles from their physick, and their excrements mixing with the air that continues always the same (because we dare not in cold weather open any place to let in fresh air) vitiate the air more and more; and the patient has the infection of the air to struggle with, as well as his distemper; which often occasions the death of those that are sick, and sometimes that of such as visit them pretty much. Now if fresh air from the hollows of the chimney be let into the sick man's room, of what degree of heat is thought most proper, it will drive out the corrupted air, and so take off all the inconveniences which must necessarily be occasioned by air impregnated with too many poisonous particles. Besides, since we can give the patient what degree of warmth we please, there will be no need of loading and choking him up with blankets after the usual manner. . . . It is a mistake in those who would be affected with the same degree of heat to have their room just so hot as to keep the thermometer at the same degree; because they shall be differently affected, according to the greater or less natural heat of their bodies at that time."

When in 1723 Dr. Desaguliers was requested to improve the ventilation of the House of Commons, his first scheme was to retain Sir Christopher Wren's holes and pyramids, but to carry tubes from these to chimneys, and to heat the tubes by means of fires. When these fires were lighted early, so that the tubes and chimneys were thoroughly heated before the House was in session, the upward currents were maintained; but the housekeeper, Mrs. Smith, disapproved of the new plan, which interfered with her rooms, and she prevented it from working by forgetting to light the accelerating fires until the House was crowded and hot.

The doctor then turned his attention to mechanical means for drawing out foul or forcing in fresh air, including several kinds of pumps and blowing wheels or fans, one of which last he arranged for the House of Commons in 1736. The plan of this wheel is shown in Fig. 1 and Fig. 2, copied from Meikleham's work above referred to.

The wheel shown in Fig. 1 and Fig. 2 is described to be 7 feet in diameter and 1 foot wide. The 12 radiating partitions *a a*, approached to within 9 inches of the axis, leaving a circular opening *z*, 18 inches in diameter. The wheel was inclosed in a concentric case *i*, which had a "blowing pipe" *m*, on the upper part of its circumference, and a suction pipe *n*, that communicated by a funnel *d*, with the central opening *z*, in the wheel, which was turned by a handle *e*, attached to the axis *c*, that went through the case and rested on a standard. The "fanner" was adjusted to revolve easily, but as closely to its concentric casing *i*, as possible, and it had no communication with the air except through the suction and blowing pipes. By the revolution of the wheel, the air entering through the central opening into the spaces

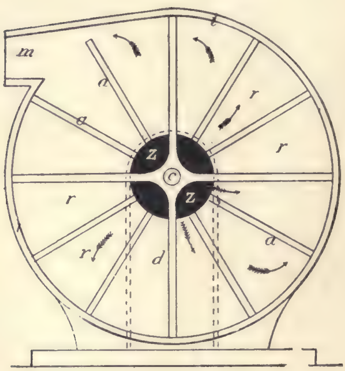

FIG. 1.

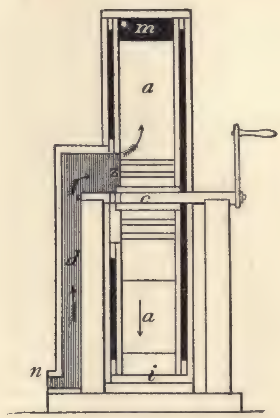

FIG. 2.

r r, formed by the radiating partitions, was thrown by the centrifugal motion towards the circumference, where it was confined by the concentric casing, and carried round until it arrived at the opening of the blowing pipe *m*, into which it was impelled by each radiating partition in continuous revolution. When the suction pipe *n*, was open to the atmosphere or to a space containing heated air, and the blowing pipe connected with a room, the apartment was filled with cold or with heated air, in any desired quantity, by increasing or diminishing the speed of the wheel. If foul air had to be drawn out, the suction pipe was connected with the room and the blowing pipe with the atmosphere ; and when it was not required either to draw out foul or introduce fresh air, but to keep the air of the room in motion only, the

suction and blowing pipe both opened into the apartment. This contrivance, with some minor changes, appears to have remained in use for 80 years.

At the request of the Lords of the Admiralty, he then undertook to make a similar wheel to be tried on one of the ships of the Royal Navy, attention having been attracted to the foul and offensive condition of these ships, and to the great prevalence of infectious fever among the soldiers embarked on them. At that time the windsail was the only means of securing fresh air in the hold of a ship, and in calm weather this was, of course, useless. But the Surveyor of the Navy, Sir Jacob Ackworth, who was directed to report on Desaguliers' machine, did not believe in such new-fangled contrivances, and, having arranged a time for the experiment when there was plenty of wind, demanded a trial of the machine against his favorite windsails. As the wheel was a very small one, with pipes only 3 by 5 inches, while the tube of the windsail was between 2 and 3 feet in diameter, this contest was, of course, declined. Sir Jacob told the engineer that he was sorry the doctor's wheel succeeded no better, for he thought it might be a very pretty thing in a house; and the doctor says: "Now, let every impartial person judge whether I have not reason to complain, for not one of the Lords of the Admiralty, who talked of having many of these ventilators made for the preservation of the health of the persons then going to Jamaica, condescended to witness the experiment, and Sir Jacob, who condemned the thing, would not once be present to observe its operation; and thus ended my scheme, which I hoped would have been of great benefit to the public."

About this time the Rev. Stephen Hales, perpetual curate of Teddington and rector of Faringdon, became a frequent contributor to the *Philosophical Transactions*, and had much to say on the subject of ventilation. He declared that if the immoderate use of spirituous liquors was less general, and the benefits of ventilation more generally known and experienced, mankind would surely become better and happier. In 1758 he published a treatise on ventilators in two parts, forming a volume of over 400 pages, octavo. This was largely concerned with the ventilation of ships by the use of inject and exhaust pumps, which were arranged somewhat on the principle of the blacksmith's bellows. These bellows were sometimes very large, being 10 feet long, and were arranged so that certain chambers might be ventilated at one time and certain others at another. He first applied the machine to the County Hospital and County Jail at Winchester; afterwards to the Savoy Prison, and subsequently to Newgate. The great practical

objection to the ventilating bellows of Dr. Hales, and to the ventilating wheel of Dr. Desaguliers, was the necessity of working them by manual labor, although in certain vessels there appears to have been no objection of this kind. In a letter from Captain Ellis, published in the *Philosophical Transactions*, Vol. XLVII., 1750–51, he states that "the bellows were far from inconvenient, and afforded good exercise for the slaves, and a means of preserving the cargo and lives." This treatise on ventilators was translated into French by a French physician. There does not seem to have been the best of feeling existing between Dr. Desaguliers and Dr. Hales. The latter, in his first announcements, makes no mention of his predecessor's contrivance, although one of the wheels had been furnished him; and in his book on ventilators, in 1758, he refers to the blowing wheel of the House of Commons disparagingly as being not specially new, and not as satisfactory as his own arrangement. He, however, in his turn was disparaged by another rival ventilator, Mr. Samuel Sutton, a brewer, who, in the year 1739, learning that the sailors on board the fleet were so dangerously ill for want of fresh air that they were put ashore to recover their health, and that the ships stunk to such a degree that they infected one another, undertook to do all that was possible for their relief, and for this purpose he proposed to withdraw the foul air out of the ships by means of pipes connected with the kitchen or galley fire, instead of using mechanical ventilators. He shut off the ordinary supply of air to the fire, and led tubes from the ship's hold to the ash pit below the fire. He obtained a patent for this arrangement, and then proceeded to visit Sir Jacob Ackworth, the same naval officer who had dealt with Dr. Desaguliers. Sir Jacob made an appointment for Mr. Sutton to call upon him at a future day, and then allowed him to wait about until evening, after which he saw him, and after a little conversation told him that no experiment should be made if he could hinder it. Mr. Sutton, however, was a business man, and had some influence at court and no scruples about using it, so that he succeeded in getting an order from the Admiralty to have his contrivance tested; but it was only through the influence of Dr. Mead, Physician to His Majesty and the President of the Royal Society, that a trial was actually made. Mr. Sutton's pamphlet, entitled, "An Historical Account of a New Method for Extracting the Foul Air Out of Ships," of which a second edition was published in London in 1749, is very entertaining reading, but contributes nothing to the practical knowledge of methods.

The improvements in heating apparatus, fireplaces, etc., made by Franklin, Rumford and others, brought with them some additional

arrangements for air supply; but very little was done in the way of ventilation, and the Houses of Parliament remained substantially in the same condition until the year 1811, when Sir Humphrey Davy undertook to improve the warming and ventilation of the House of Lords. His plan was to admit the fresh warm air through a large number of holes in the floor, and to withdraw the foul air at the ceiling through two apertures covered with open wire work, from which metal tubes were carried to the external air, and when extra ventilation was required these tubes were heated to accelerate the velocity of the air passing through them. He seems to have badly calculated the diameter of the tubes necessary to carry off the air, each of which was only 1 foot square, so that his plan became a total failure. The exact number of the perforations in the floor, as well as the fee received, is recorded in two lines of an epigram given by Meikleham:

> "For boring 20,000 holes,
> The Lords gave nothing—d——n their souls."

The horizontal heating flues beneath the floor were 14 inches wide, 18 inches deep, and nearly 100 feet long. These gradually cracked, and permitted some of the furnace gases to escape into the hall; and finally, in 1834, when a large quantity of waste paper was burned, the woodwork in the vicinity took fire, and both Houses of Parliament were destroyed.

The next to try his hand at improving the ventilation of the House of Commons was the Marquis de Chabannes, who used steam, both for warming the air to be introduced and for heating accelerating coils placed in the exhaust ducts above the ceilings, having previously tried a somewhat similar system at Covent Garden Theatre. The single main foul air shaft rising perpendicularly from above the ceiling of the hall of the House, had branches from openings in different parts of the ceiling, was heated by steam cylinders placed near its base and terminated above the roof in a cowl 4 feet in diameter.

The use of steam for heating and ventilating was especially urged by Mr. Thomas Tredgold, an English engineer, who published in 1824 a treatise entitled, "Principles of Warming and Ventilating Public Buildings, Dwelling-houses, etc." This went through three editions, and was a standard authority on the subject—in fact, his formulæ for proportioning supply of air-heating surface, etc., are still in use among certain heating engineers.

As the result of calculations as to the various causes of impurity of air produced by respiration, perspiration, etc., he concluded that

each person should be allowed 4 cubic feet of fresh air per minute—or less than one-tenth the amount actually required—and this error has been copied in a number of later works.

Taking this as a basis he goes on to give his working formulæ as follows:

"The most difficult season for ventilation is the summer; and we may consider that there should not, in warm weather, be a difference of temperature exceeding 10 degrees; and with this limit as to variation of temperature, we shall have this rule for the area of the tubes.

"Rule.—Multiply the number of people the room is to contain by 4, and divide this product by 43 times the square root of the height of the tubes in feet, and the quotient is the area of the ventilator tube or tubes in feet." Again,

"Rule.—In public buildings, dwelling houses, etc., the quantity of air in cubic feet to be warmed in one minute should be equivalent to four times the number of people the room is intended to contain, added to eleven times the number of external windows and doors, added to one and a half times the area in feet of the glass exposed to the external air." This number of cubic feet of air to be heated is, by another rule, "to be multiplied by the difference between the temperature the room is to be kept at, and that of the external air, in degrees of Fahrenheit's thermometer, and divide the product by 2.1 times the difference between 200 and the temperature of the room; this quotient will give the quantity of surface of cast-iron steam pipe that will be sufficient to maintain the room at the required temperature."

"If the cubic feet of space in a room be divided by the quantity of air to be warmed in one minute to sustain its temperature, the quotient will be nearly the number of minutes it will require to raise it to a given temperature, the ventilation being stopped during the time."

These examples are sufficient to indicate why the work of Tredgold has continued to enjoy so great an authority among those engaged in the business of heating and ventilating. Its precepts are positive and definite. There are no exceptions. It is assumed that the construction of all buildings is alike and of the best character, and that the temperature of the external air varies only between comparatively close limits,—in fact, those of the English climate—and that any amount of foulness of air which can be endured is not unhealthy. The formulæ of Tredgold, as has been stated, appear slightly modified in many engineering manuals, French, German, English and American, although their source is by no means always acknowledged. We shall have occasion to comment upon the fundamental principles of his formulæ

in speaking of the quantity of air to be supplied and of heating surface to be provided.

In 1838, Dr. Neil Arnott published a little book on warming and ventilating, which was devoted chiefly to the description, and advocacy of the use, of his self-regulating stove. As he assumed that from 2 to 3 cubic feet of air per minute was a safe and sufficient supply for each person, it is not surprising that he should think that many people demand too much. He says, "There are, in England, many persons who, under all circumstances, call out for open fires and open windows, and by the cold currents and other concomitants of a ventilation more than necessary, prodigiously waste fuel and injure or kill their children and friends by catarrh, rheumatism, etc." In later years Dr. Arnott became convinced that 2 or 3 cubic feet of air per minute are not enough—but all his views of the subject are from the point of view of an ingenious mechanician and physicist—with little reference to the physiological needs of the living human body.

A very valuable work on heating is that of Mr. Hood, the first edition of which appeared in 1837, and was devoted mainly to heating by hot water. The fifth edition appeared in 1879. Ventilation is only considered incidentally.

In 1835 Dr. David Boswell Reid was employed to improve the heating and ventilation of the Houses of Parliament, the old systems of which had been destroyed by fire. As the result of experiments made in Edinburgh, he decided that the quantity of air to be warmed and passed through the chamber must be much greater to secure satisfactory results than any of his predecessors had supposed to be necessary, and that the area of clear opening for discharge of air should be 50 square feet, instead of 19 square feet, as had been provided by the Marquis de Chabannes. He provided for the greatest possible diffusion of the incoming air, having nearly a million of perforations in the floors, seats, etc., for that purpose, and made elaborate arrangements for filtering, warming and tempering the air supply. The results appear to have been very satisfactory, and Dr. Arnott's statement was no doubt correct, that "Until the late House of Commons existed as ventilated by Dr. Reid, there was never in the world a room in which 500 persons or more could sit for ten hours in the day, and day after day, for long periods, not only with perfect security to health, but with singular comfort."

Dr. Reid published the results of his experiments and observations in 1844, in the form of a large octavo volume entitled, "Illustration of the Theory and Practice of Ventilation, etc.," which is still

one of the most suggestive and interesting works in existence on this subject. When the new Houses of Parliament were constructed Dr. Reid was employed to arrange their heating and ventilation, but became involved in controversies with the architect, and the result was that he lost his position. He then came to the United States, and in 1858 published at New York a work entitled, "Ventilation in American Dwellings," which, however, was not a success. He was succeeded as "ventilator" to the Houses of Parliament by Mr. Gurney, who advocated downward ventilation, ventilation by steam jets, and several other schemes, some of which were tried and proved failures; while others were never tried. The principal change which he made was in the use of steam heat instead of hot water. He was succeeded by Dr. Percy, whose reports on the ventilation of the Houses of Parliament are among the best of this kind of literature.

In 1856, the General Board of Health, of England, appointed a commission to inquire into the best practical methods of warming and ventilating dwelling-houses. The report of this commission, which was composed of William Fairbairn, James Glaisher and Charles Wheatstone, was published as a folio blue book, in 1857. Prof. Lyon Playfair, who had been named on the commission, was unable to serve. This report deals mainly with the results of experiments on various forms of grates and stoves suitable for heating dwelling-houses, and the most interesting part of it as regards ventilation is given in the appendix in the form of a paper on the Chemical Relations of Ventilation, by Henry E. Roscoe, in which are given the results of a number of experiments made by himself, and also of a number made by Professor von Pettenkofer, in Munich. Professor Roscoe remarks that there is great need of precise information upon two points—viz.: 1. When is, and when is not, a closed inhabited atmosphere unhealthy? 2. How much ventilation or change of air is effected in a particular room from what may be termed accidental sources—that is, from leakage, permeation of walls, opening of doors, etc.? To the first question he replies that no definite answer can be given. As regards the second, he concludes that the amount of ventilation from accidental sources is larger than had been supposed, but that, "under all circumstances, an artificial ingress for fresh air is essential." The special value of his work consists in the introduction of the carbonic acid test, as employed by von Pettenkofer, as a measure of the amount of ventilation actually going on.

The writings of Frederick Edwards, Jr., upon grates, fireplaces, chimneys, etc., which appeared between 1864 and 1870, are all worth

reading, and especially so is his treatise on the ventilation of dwelling-houses, published in 1868.

In France the history of ventilation has been mainly connected with its application to hospitals, and when, towards the end of the eighteenth century, Lavoisier announced his discoveries of the chemical composition of the air and the physiological importance of oxygen, it was to hospitals that he suggested the application of the practical conclusions to be drawn from these discoveries by undertaking to furnish a constant supply of fresh air to the inmates. According to Bertin-Sans (Dict. ency. des sc. med., Series V., Vol. 2, Paris, 1886, article "Ventilation"), the first trace of a project for the ventilation of a public building in France is found in 1840, when Darcet proposed to ventilate the Necker Hospital in Paris, but the plan was not carried out. In 1843, in his "Traité de la chaleur," Peclet states that the only hospital in France that had ventilating arrangements was that of Alais.

In 1846 a system of ventilation combined with heating, known as *le système Duvoir*, was applied to one of the pavilions of the Hospital Beaujon, and a number of experiments and observations made on this showed that, under ordinary circumstances, 60 cubic meters of air per bed per hour was scarcely sufficient, and that in the surgical wards it was not sufficient to keep them free from odor.

In the construction of the Hospital Lariboisière in 1853 two systems were tried, one of aspiration, the other of insufflation, the results being, according to Grassi's report, in favor of the latter, but neither of them were entirely satisfactory—for neither of them was arranged to provide a sufficient quantity of air.

In Germany, as in France, some of the most important contributions to ventilation have been made in connection with hospital construction, and especially in the plans of large hospitals constructed in recent years in Berlin and Hamburg. The descriptions and plans of the Berlin City Hospital at Friedrichshain, and of the Military Hospital at Tempelhof, both prepared by the architects, Gropius & Schmieden, are especially interesting in this respect.

The principal systematic German work on the subject is that of Wolpert, the title of which is given in the list at the end of this chapter.

The investigations into the sanitary condition of the English Army, which inquiries were brought about by the heavy losses of the Crimean War, and the resulting reports of the Commission on the sanitary state of the army made in 1857, and of the Commission thereupon appointed for improving the sanitary condition of barracks and

hospitals were the means of directing special attention to the importance of sufficient air supply as a means of preserving the health and efficiency of troops. Between 1857 and 1860 the experiments of von Pettenkofer, Roscoe and other physiologists and chemists had shown that the old ideas as to the amount of air required to so dilute the exhalations of men that there should be no unpleasant odor—were totally inadequate—and the data collected by the Army Sanitary Commission showed that ill health and excessive mortality prevailed among the troops in proportion to the defects in the air supply of their barracks. The Barracks Commissioners fixed 20 cubic feet of fresh air per minute, or 1,200 cubic feet per hour per man as the minimum requirement. In 1860 General Morin gave the figures required for barracks as 1,059 cubic feet per hour by day and twice that amount at night for each man, and in the first edition of his "Manual of Hygiene," published in 1864, Dr. Parkes states that at least 2,000 cubic feet per hour must be given to entirely free the air from unpleasant odor.

From this time on it has been well known to those familiar with the subject that to secure satisfactory ventilation large amounts of air must be introduced and distributed, and it is the settlement of this point that has done away with much of the useless theories and speculations of former years. It is mainly to the teachings of von Pettenkofer and his school that what may be called the chemical test for ventilation has come into use during the last 25 years, and is now the one that is chiefly relied upon, as will be explained in a future chapter.

One of the most valuable manuals on ventilation is "A Practical Treatise on Ventilation and Warming," by Dr. Morrill Wyman, published in Boston, in 1846. In a comparatively brief space it sums up what is really useful of the work of Péclet; states the general principles of ventilation in a clear, concise style, and in a form which, as a means of instruction for the ordinary reader, can hardly be surpassed; gives good illustrations of the methods used in various kinds of buildings, and of the results obtained, and is one of the few books on heating and ventilation which advocates no patent or proprietary apparatus.

Of later American writers on this subject, I will refer to but two—Mr. Robert Briggs, a well-known American engineer, who died in 1882, and Mr. Baldwin, who is still living. Mr. Briggs was a practical mechanical engineer, who was for a number of years in charge of the works of a large manufacturing establishment in Philadelphia, and had much to do with the making of steam-heating apparatus and of fans for mechanical ventilation. He wrote no systematic treatise on

the subject, but presented some valuable papers before engineering societies, and contributed much interesting matter to the earlier volumes of *The Engineering Record*, and in this way, as well as through those trained in the shops under his direction, he has exercised a very considerable influence on the details of apparatus and methods employed in the Middle and Western States for heating and ventilating during recent years.

Mr. Baldwin has also written much on heating for *The Engineering Record*, and his books on steam and on hot-water heating are standard authorities for American practice, and incidentally include some interesting matter relating to the ventilation of particular buildings.

On the subject of heating and ventilating legislative assembly halls several reports of interest have appeared in the United States. Among these may be mentioned the report of the Committee on Public Buildings of the House of Representatives of the State of Massachusetts upon the ventilation of Representatives' Hall, made April 2, 1849; the report of the Special Committee of the same House upon the same subject made in January, 1865; the report upon the ventilation of both Houses of Congress, presented to the House of Representatives in 1866; the report on the ventilation of the Hall of the House, presented to the House of Representatives in February, 1878, and the report presented to the same body in June, 1884.

Of the above, the Massachusetts Report of 1865, is mainly an argument in favor of downward ventilation. The report made to Congress in 1865 is especially valuable because it contains the results of an extended series of observations and air analyses made by Dr. Charles M. Wetherell in the Halls of Congress under different circumstances. With the official reports on the ventilation of the Capitol at Washington should be mentioned the report of Mr. Robert Briggs on this subject, made in 1876, in which the original plans for heating and ventilation are described. The conclusions of these reports will be given in the description of the ventilation of the House of Representatives which will be found in a subsequent chapter of this book.

The following is a list of some of the more important and interesting books relating to ventilation which have been published up to the present time. Other works and papers relating to the ventilation of mines and of special classes of buildings will be referred to in the chapters devoted to those subjects.

Gauger (N.)—La mécanique du feu, ou l'art d'en augmenter les effets, and d'en diminuer la dépense, Contenant le traité de nouvelles cheminées [etc.], par N. G * * * . X , 267 pp., 4 l., 12 pl., 8vo. Amsterdam: 1714.

——— Fires Improved; or, A New Method of Building Chimneys, so as to Prevent their Smoking. 158 pp., 8vo. London: 1736.

Hales (Stephen)—A Description of Ventilation; whereby great quantities of fresh air may with ease be conveyed into mines, gaols, hospitals, work-houses and ships, in exchange for their noxious air. An account also of their great usefulness in many other respects; as in preserving all sorts of grain dry, sweet, and free from being destroyed by weevels, both in granaries and ships, and in preserving many other sorts of goods; as also in drying corn, malt, hops, gunpowder, etc., and for many other useful purposes, which was read before the Royal Society in May, 1741. 8vo. London: 1743.

——— A Treatise on Ventilators. In two parts. 111, 346 pp., 8vo. London: 1758.

Genneté.—Purification de l'air croupissant dans les hôpitaux, les prisons, et les vaisseaux de mer. 113 pp., 1 pl., 8vo. Nancy: 1767.

Report of the Committee of the House of Commons on Ventilation, Warming, and Transmission of Sound; abbreviated, with notes, by W. S. Inman. London: John Weale. 1836.

Ure (A.)—An Experimental Inquiry into the Modes of Warming and Ventilating Apartments, in Reference to the Health of the Inmates. 8vo., n. p. 1836.

Tredgold (Thomas)—The Principles of Warming and Ventilating Public Buildings, Dwelling-Houses, Manufactories, Hospitals, etc. Third edition, to which is now added an appendix by T. Bramah, on Heating by Means of Warm Water, etc. 324 pp., 12 pl., 8vo. London: 1836.

Arnott (N.)—On Warming and Ventilating, with Directions for Making and Using the Thermometer Stove. 8vo. London: 1838.

Reid (David Boswell)—Illustrations of the Theory and Practice of Ventilation, with Remarks on Warming, Exclusive Lighting, and the Communication of Sound. XX., 451 pp., 8vo. London: 1844.

Bernan (W.)—[Meikleham (R.)].—On the History and Art of Warming and Ventilating Rooms and Buildings by Open Fires, Hypocausts, German, Dutch, Russian and Swedish Stoves, Steam, Hot Water, Heated Air, Heat of Animals, and Other Methods. 2 vols. in 1, 12mo. London: 1845.

Wyman (Morrill)—A Practical Treatise on Ventilation. XVI., 419 pp. Boston: 1846.

Report (Second) From the Select Committee on Ventilation and Lighting of the House (with Minutes of Evidence and Appendix). 670 pp., roy. 8vo. London: 1852.

Péclet (E.)—Nouveaux documents relatifs au chauffage et à la ventilation des établissements publics, suivis de nouvelles recherches sur le refroidissement et la transmission de la chaleur [pour servir de supplément à la seconde édition du Traité de la chaleur.] 4to. Paris: 1854.

ARNOTT (N.)—On the Smokeless Fireplace, Chimney Valves, and Other Means, Old and New, of Obtaining Healthful Warmth and Ventilation. 8vo. London: 1855.

PETTENKOFER (M.)—Ueber den Luftwechsel in Wohngebäuden. 8vo. München: 1858.

REID (D. B.)—Ventilation in American Dwellings; to which is added an introductory outline of the progress of improvement in ventilation by Elisha Harris. 8vo. New York: 1858.

PÉCLET (E.)—Traité de la chaleur considérée dans ses applications. 3 èd. 8vo. Paris: 1860–61.

RITCHIE (ROBERT).—A Treatise on Ventilation, Natural and Artificial. XVI. 232 pp., 8vo. London: 1862.

MORIN (ARTHUR).—Mécanique Pratique. Études sur la ventilation. 610, 407 pp., 16 pl., 8vo. Paris: 1863.

House of Representatives, 39th Congress, 1st Session, Ex. Doc. No. 100. Warming and Ventilating the Capitol. 96 pp., 8vo. Dated May 7, 1866.

MORIN (A.)—Manuel pratique du chauffage et de la ventilation. 8vo. Paris, 1868.

EDWARDS (F.)—On the Ventilation of Dwelling Houses and the Utilization of Waste Heat From Open Fireplaces. VIII., 168 pp., 8vo. London: 1868.

GREAT BRITAIN, COMMISSIONERS OF PATENTS. Patents for Inventions, Abridgments of Specifications Relating to Ventilation. A. D. 1632–1866., 12mo. London: 1872.

DEGEN (L.)—Practisches Handbuch für Einrichtungen der Ventilation und Heizung in Öffentlichen und Privatgebäuden nach dem System der Aspiration. Unter Zugrundelegung von Morin's Manuel du Chauffage et de la Ventilation. 2d., 8vo. Müonchen: 1878.

House of Representatives, 45th Congress, 2d Session. Report No. 119. Ventilation of the Hall of the House. 16 pp., 8vo. Dated February 4, 1878.

HOOD (C.)—A Practical Treatise on Warming Buildings by Hot Water, Steam and Hot Air, etc. 5th ed. London: 1879. (First edition was in 1837.)

VALERIUS (H.)—Les applications de la chaleur, avec un exposé des meilleurs systèmes de chauffage et de ventilation. 8vo. Paris: 1879.

PLANAT (P.)—Cours de construction civile, Première partie ; Chauffage et ventilation des lieux habités. 4to. Paris : 1880.

WOLPERT (A.)—Theorie und Praxis der Ventilation und Heizung. 2, Aufl., 8vo. Braunschweig : 1880.

PUTNAM (J. P.)—The Open Fireplace of all Ages. 8vo. Boston : 1881.

BILLINGS (J. S.)—The Principles of Ventilation and Heating, and Their Practical Application. 8vo. New York : 1884.

Reports (first and second) from the Select Committee on the Ventilation of the House. Folio. London : 1886.

Traité de physique industrielle, production et utilisation de la chaleur, par L Ser. Tome II. 2d part avec la collaboration de M. M. L. Carelle et E. Herscher. 8vo. Paris : 1892.

CHAPTER III.

THE ATMOSPHERE.

COMPOSITION AND PHYSICAL PROPERTIES.

THE atmosphere is the gaseous envelope which surrounds the earth, forming an aerial ocean in which we move about. This atmosphere is a mixture of gases and vapors, two of which, oxygen and nitrogen, make up the great bulk and are found everywhere in almost constant proportions. Besides these there are always present carbonic acid, watery vapor, and ammonia, or some of its compounds. As the result of a vast number of analyses made in different parts of the world, the proportions of the different ingredients in normal air are found to be in 100 parts by volume, an average of nitrogen, 78.30; oxygen, 20.70; carbonic acid, 0.03; water, 0.8 to 1.0; ammonia, a trace. The principal variations from this mean in different localities consist in increase in the proportions of carbonic acid, water and ammonia, and in the addition of various other gases, which last, however, may be considered as merely local impurities. The normal atmosphere is not a chemical combination of the different factors composing it, but a mere mechanical mixture. If it were a chemical compound of definite composition, the problems of ventilation would be of a very different nature from those presented under existing circumstances. The mixing of these constituents due to changes in temperature, mechanical action of winds, and to natural diffusion between gases of different natures is so perfect that analyses of the external air in the most widely separated localities give results which vary but little from the above figures. The proportion of oxygen and nitrogen in the air taken near the surface of the sea many miles from land, or upon mountain tops, differs as to the proportion of the oxygen and nitrogen which it contains in hardly an appreciable degree from that taken in the streets of a city or over the prairies of the West. The perfection of this mixing of the gases in the atmosphere is shown by the results obtained by air analyses made in large cities. If we take the city of London, for example, it is estimated that 90,000 tons of carbonic acid are thrown into its atmosphere

daily, and yet analyses of the air at this place show an increase of not mor than one part in 10,000 of this gas over the proportion found in the suburbs or rural districts. The uniformity of the mixture, however, only obtains in places where the air is free to move in every direction under the action of differences of temperature or of winds coming from without. In places more or less inclosed, where the winds have no action, such, for example, as sewers, or inclosed courts, and where decomposition of organic matters is going on, various substances may be added to the air in such proportions as to become susceptible of analysis and necessary to be considered in respect to the comfort and health of those living in the vicinity. Among these may be grouped carbon monoxide, ammoniacal compounds, sulphuretted hydrogen and sulphuric and sulphurous, nitric and nitrous acids. In deep wells the proportion of carbonic acid which gains entrance from the surrounding soil may reach very high proportions, since the only method of removing the excess is through the process of diffusion, which is overbalanced by the rate of production of this gas. Thus accumulation of this gas results, which may render the air of the well incapable of supporting respiration or of maintaining the flame of a candle, although the upper part is freely open to the external, comparatively pure air.

Among the constituents of the atmosphere, although subject to great variations, it has been usual to reckon a gas known by the name of ozone, which by most chemists is considered to be an allotropic form of oxygen. As prepared in the laboratory this is characterized by a peculiar odor and by having special oxidizing powers, and its presence in the atmosphere has been considered so important a matter that special methods have been devised for its quantitative estimation, and at certain meteorological stations a daily record of its variations has been kept. It has, however, long been known that the methods of testing for it are liable to produce great errors, and a recent work upon the subject seems to indicate that much, if not all, of what have been supposed to be the characteristic reactions of ozone in the air are really due to nitrous acid,[1] and that it is very doubtful as to whether the supposed allotropic oxygen exists in the free atmosphere.

Of the fundamental factors, nitrogen and oxygen, going to make up our air, the nitrogen possesses apparently no hygienic significance whatever. Its only office seems to be the dilution of the otherwise too energetic oxygen. It plays no direct biological rôle in either the

[1] Ilosva, Bull. soc. Chimique de Paris, September and November, 1889.

animal or vegetable kingdom, and is therefore from a hygienic standpoint of but little interest.

The oxygen, on the other hand, is of most vital importance to all living things—without it life would cease. Fortunately the stock of oxygen existing in the air is so great and the provisions for its constant circulation so perfect that there is but little fear of its exhaustion.

Throughout the animal kingdom oxygen is essential to the tissue changes which go to make up what we understand as life. As a result of its action upon the tissues of the animal bodies certain products are given off, most conspicuous among them being the carbonic acid thrown off from the lungs in the process of respiration. Some idea of the amount of carbonic acid given off daily by the animal world may be formed when one considers that from each adult human being it is estimated 464.4 litres (16.25 cubic feet), are excreted in 24 hours.

No doubt the influence of this daily pollution would after a time be felt by the inhabitants of the earth, were it not for the peculiar functions of certain of the vegetable kingdom.

Many members of the plant world—those containing the green coloring matter known as chlorophyl—under the influence of sunlight have the power of taking up this carbonic acid, working it over in their tissues, and giving out free oxygen as an excretory product. In this way a constant proportion in the amount of this all-important gas in the air is maintained. So great is the stock of oxygen in the air, and so active its reproduction by the chlorophyl-containing plants, that its exhaustion by animal life is quite out of the question.

It has been estimated that if all vegetables should cease to reproduce this gas, and animal life continue as it now is, that about eighteen thousand years would be necessary for a reduction of 1 per cent. in the amount of oxygen now present in the air.

It is, however, quite possible that a change in the proportion of oxygen may ultimately be produced by the burning of fuel. In the *Lancet* of August 12, 1882, Dr. T. H. Walker takes the ground that the carbon formerly extracted out from the atmosphere and stored up in coal is now being rapidly returned to it chiefly through the influence of the combustion of coal. Animal respiration and the decay of plants have very little permanent influence on the amount of carbonic acid in the atmosphere, for it is simply a process of circulation, and the animal only gives back to the atmosphere what has previously been absorbed by the plants on which the animal feeds. In the burning of limestone, there is simply a return to the air what the animals from the shells of which the limestone is built up have pre-

viously absorbed. A certain amount is given out by volcanoes and caverns in the depths of the earth, but this is of small importance. The amount of coal annually consumed throughout the world is estimated by Bessemer at 400,000,000 tons, giving 336,000,000 tons of carbon, thus giving out 1,232 million tons of carbonic acid annually to the atmosphere. The total weight of the atmosphere is estimated at 5,210 billion tons, including about three billion tons of carbonic acid. He concludes that the air will become injurious to life from the influence of carbonic acid when one-sixth part of the coal known at present is consumed.

The possibility of such an increase of the proportion of carbonic acid in the atmosphere as to have a definite influence upon the vegetable and animal life of the globe, said increase being due to the combustion of the available coal, has also been discussed by General Isaac J. Wistar, in a paper contained in the Proceedings of the Academy of Natural Sciences of Philadelphia, for January 26, 1892. He concludes from the data given that the amount of mineable coal may be taken as equal to nearly 1 inch in thickness over the land surface of the earth, and that if this thickness be taken as .8371 inch its complete combustion would remove 1 per cent. of the free oxygen of the atmosphere and add to the air a little over three-tenths of 1 per cent. by weight of carbonic acid.

Supposing these premises to be correct, it is possible that some compensatory changes in animal organization would follow, but the direct result of this change in the composition of the air would, of course, be very gradual. As will be seen in the section relating to carbonic acid determinations, there is no evidence of any increase in its proportion in the atmosphere within the last 30 years, during which the combustion of fuel has been at its height, and until such increase to the amount of 1 part in 10,000 has been demonstrated, it will not be worth while to sound an alarm and attempt to check the consumption of fuel for this reason only.

The amount of carbonic acid in the atmosphere arising from the manifold processes incidental to life in both animal and vegetable kingdoms, and to the many chemical changes both natural and artificial constantly going on over the surface of the earth is found to experience only a very slight variation. In general, an average of from 3 to 4 parts in 10,000 parts of air may be taken as normal. As stated above, under certain abnormal conditions, this amount may be subjected to slight increase, but such an increase is only local and temporary, and the rise in amount is quickly caused to disappear

through mechanical action of winds and the natural diffusion constantly in progress between gases of different nature.

In these amounts the gas is of itself of no biological significance whatever. But as we shall see when we come to consider the air of inclosed spaces occupied by human beings, a rise or fall in the quantity of this gas present will indicate other parallel changes in the air which may be of the greatest moment.

A further, and perhaps the most variable normal constituent of the atmosphere is water in the form of vapor, the amount of which increases and decreases with every rise and fall of temperature, and likewise with the opportunities present for the air to obtain moisture. On an average, the air may be said to contain between 0.8 and 1.0 part per cent per volume of water in the form of vapor. Only rarely do we find as much vapor in the atmosphere as is possible for it to hold. When such a condition exists the air is said to be "saturated," that is, for the existing temperature there is so much invisible vapor present that the slightest decrease in the temperature results in a condensation of a portion of the vapor in the form of visible water. This point, at which the air can not take up more vapor at the existing temperature, or loses a portion of its vapor by condensation if its temperature be but slightly reduced, is known as its "Dew Point."

The relative amount of water present in air which is not saturated is usually expressed in per cent. of what the air should contain at the existing temperature were its condition that of saturation. This amount is expressed by the term "Relative Humidity." The actual amount of water present in air at any moment, regardless of saturation, is known as its "Absolute Humidity."

The variations in the amount of aqueous vapor which are seen to occur in the air at different points on the earth's surface are very great, the least being present at inland places of constantly low temperature, the greatest amount being found to co-exist with large water surfaces and constantly high temperature. In the first case it is plain that but small amounts of vapor should be expected in the air; whereas, under the latter conditions both the extent of water exposed and the elevated temperature favor evaporation, and hence an increase in the degree of humidity in the surrounding atmosphere. For the same place, daily fluctuations in the humid condition of the air are seen to occur. These diurnal variations are found to follow certain regular and definite laws dependent in most cases upon temperature changes.

For points on the sea coast, or near large bodies of water, the absolute humidity of the air is found to experience a gradual increase

from sun-rise until about 2 o'clock P. M., when a corresponding diminution sets in and continues until sun-rise again.

For inland places the same general law may be laid down for the winter months, but in summer the curve, if the variations are represented graphically, will experience a slight fall and rise between the hours of 4 and 6 o'clock P. M. After 6 P. M. the decrease in the amount of vapor is gradual until sun-rise the following morning, when nearly the same condition should be found as existed at the same hour on the previous morning.

In addition to the normal and accidental constituents of the air which have already been mentioned, there are constantly present solid particles. These solid matters, which vary in amount with changing atmospheric conditions, are for the most part simple microscopic particles of inorganic matter, in the form of dust, the result of wear and tear upon the earth's surface, or they may be of organic origin and possess distinct biological characteristics. When in this form they are, for the most part, vegetable in nature, and represent the family of bacteria. The great majority of bacteria found in the air are not floating free as single separate individuals, but are deposited upon larger dust particles. In very exceptional cases, these organisms may possess the power of producing disease, but, as a rule, it may be safely said that the bacteria found in the open air are of an innocent nature, and indeed, play the part of benefactors to humanity. It is through the agency of these innocent saprophytes that complex dead matters are reduced to their simpler elementary forms and returned to the earth to serve as nutrition for more highly organized plants.

It is, of course, not impossible for disease-producing organisms to find their way into the free atmosphere, but here they meet with so many conditions unfavorable to their existence, and are distributed through such an enormous volume of air that their detection is extremely improbable. In the air of rooms or hospital wards containing patients suffering from infectious diseases, the conditions are quite different, as will be seen when we come to treat of this part of our subject.

From what has been said, it is seen that our air is fundamentally a mixture of two gases, nitrogen and oxygen; that there is constantly present a pollution of from 3 to 4 parts of carbonic acid gas to 10,000 parts of air; that water vapor in varying amounts is present in most places; that solid particles, in amount depending upon varying atmospheric conditions, and of both organic and inorganic nature, are to be found, and, in addition, a variety of accidental gaseous contaminations may now and then be detected.

What has been said thus far refers entirely to the air as we find it in "the open," that is, to the free atmosphere. An acquaintance with it in this condition is essential before attempting to study alterations in its constitution resulting from processes of life.

In connection with the mechanics of ventilation, which deal largely with movements of air, and the means of producing, directing and regulating them, the physical properties of the air are more important than its chemical composition, and it is necessary to study these in their relations to different conditions of temperature, pressure and presence of vapor of water. Air has weight, and the weight of a given volume of air differs under different circumstances. A given volume, for instance a cubic foot, weighs more when it is dry than when it contains moisture if the temperature and pressure be the same; it weighs more at a lower temperature than at a higher one if the pressure and moisture be the same, and its weight increases with the pressure if the temperature and moisture be the same. Hence, to determine the weight of a given volume of air by comparing it with a standard fixed by experiment, it is necessary to know not only the volume but the temperature, pressure and proportion of contained watery vapor of the air to be measured. And since most of the movements of masses in the air in the form of currents, with which ventilation is concerned, are due to differences in weight between adjacent equal volumes of air, it is desirable that the causes of these differences should be understood, and the means of measuring their effects be at the command of those who are to deal with problems of this kind.

First, then, as to effects of temperature. When air which is free to expand, or which, in other words, is under constant pressure, is heated, it increases in volume according to a definite law which is, that for each degree of temperature added to its heat it expands a certain constant fraction of its own volume, the figure representing which is known as the co-efficient of expansion. This co-efficient is for air 0.003667 for each degree centigrade from 0.° C., to 100° C., or on the Fahrenheit scale, it is 0.00236 for each degree between 32° and 212° F. For example, 1 cubic centimeter of air at 0.° C. will make 1.003667 c.c. at 1° C., or 1.03667 c.c. at 10° C., or at any given temperature t, it will make $1 + (0.003667\ t°)$ c.c. In like manner, 1 cubic foot of air at 32° F. will become 1.00236 cubic foot at 33° F., and at any given temperature t, above 32° on the Fahrenheit scale its volume will be found by the formula, $V = 1 + (0.00236 \times (t - 32))$. This law holds good so long as the pressure is constant, no matter what the pressure may be.

The alterations experienced by a volume of gas under varying conditions of pressure stand not in a direct relation, as in the case of temperature, but are inversely proportionate to the pressure. (Boyle's Law.) If a cubic foot of gas at one atmosphere be subjected to an additional pressure of an atmosphere, its volume will be reduced to one-half of a cubic foot; if to four atmospheres, the resulting volume will be one-quarter of a cubic foot—or, as it is generally expressed, if under a pressure of b millimetres or inches of mercury the volume of air is expressed by v, its reduced volume v_n under normal conditions of 760 m.m., or 29.922 inches of mercury may be found by the following formula:

$$v : v_n = 760 : b \text{ (not as } b \text{ to } 760), \therefore$$

$$v_n = \frac{v \,.\, b}{760}$$

or expressed in words, to reduce any volume of air at the observed barometric pressure to what it would be under the standard pressure of one atmosphere, multiply the observed volume by the observed pressure, and divide the result by the normal pressure (760 m.m., or 29.922 inches of mercury).

But, as has been said, the volume of air is affected also by temperature, and, as temperature and pressure always exist together in reducing any volume of air to standard conditions, both factors must be taken into account.

By the term, standard conditions, as applied to gases, one understands temperature, 0° C. or 32° F., and atmospheric pressure 760 m.m., or 29.922 inches of mercury.

To reduce, therefore, a body of air to these standard conditions, the two corrections pointed out in the above paragraphs are made together, as follows: We found that for each increase of 1° C. in the temperature of a gas its volume was increased 0.003667, and for an increase of $t°$ C. in temperature its volume would be expressed as

$$v + (0.003667 . t°)$$

To find, therefore, what the observed volume of a gas (v_1) at the observed temperature, $t°$ C., would be when reduced to 0° C., we have

$$v_0 : v_1 = 1 : 1 + (0.003667 . t°)$$

and not an inverse proportion as in the case of the pressure, for, as stated, the increase in volume is directly proportionate to the increase in temperature; hence

$$v_0 = \frac{v_1 \,.\, 1}{1 + (0.003667 . t°)}$$

We found now that the volume of a gas reduced from the observed conditions of pressure to the standard conditions was expressed by the formula:

$$v_n = \frac{v \, . \, b}{760}$$

this without taking the temperature into consideration.

It is more convenient to combine the two formulæ, and make both corrections at once, than to make them separately.

The result of combining the two expressions for temp. and pressure correction with a single formula will be,

$$v_0 = \frac{v_1 \, . \, p}{760\,(1 + (0.003667 . t^\circ))} \quad \text{in which}$$

v_1 = observed volume of gas.
p = observed pressure under which the gas exists.
760 m.m. = normal barometric pressure.
0.003667 = co-efficient of expansion for air.
t° = observed temperature at which the gas exists.
v_0 = volume of gas required under normal conditions of temp. and pressure.

Example.—One hundred litres of air exist at 20° C., and 720 m.m. barometric pressure (barometer reduced to 0° C., see below). What will be the volume under normal conditions? Substituting these readings into the above formula, we find,

$$v_0 = \frac{100 \times 720}{760\,(1 + (0.003667 . 20^\circ))} = 88.26 \text{ litres at } 0^\circ \text{ C., and } 760 \text{ m.m.}$$

NOTE.—Where the English measures are employed, it must be borne in mind that the normal barometric pressure is 29.922 inches of mercury, and the co-efficient of expansion for air is 0.00236 for each degree Fahrenheit, above 32°. These quantities must therefore be substituted for those given in the above formula.

Reduction of Barometric Reading to 0° *Temp.*—In considering atmospheric pressure as indicated by the height of the mercurial column of the barometer, it must be borne in mind that the variations in height of the column are due, not alone to alterations in the pressure of the air, but to a small extent to fluctuations in temperature also. Mercury follows the same general law of expansion under the influence of heat as do other bodies. It is necessary, therefore, in order to determine what proportion of the length of the mercurial column is due to atmospheric pressure alone, that the influence of

temperature be eliminated, or rather, corrected for; that is, the observed reading must be reduced to what it should be, if the existing temperature were 0° C., or 32° F. As was seen in the case of air, mercury has a constant rate of expansion—for each degree centigrade this co-efficient of expansion is 0.00018. That is, with an increase of each degree in temperature above 0° C., the expansion of the column of mercury due to temperature alone is 0.00018 of itself. If, therefore, a column of mercury whose height is b at 0° C., be subjected to an increase of 1 degree in temperature, the pressure remaining constant, it will no longer be b, but $b + (b \times 0.00018)$, if to t° C. temp. then $b + (b \times (0.00018. t°))$. If, therefore, it is desired to give an observed reading at any given temperature in terms of 0° C., temperature corrections must be made for the expansion due to the heat—this expansion must be subtracted from the observed height of the column.

If the observed height of the column due to atmospheric pressure and temperature together be represented by $b + (b \times 0.00018 \times t°)$, or, which is the same, $b\,(1 + 0.00018.t°)$, then it is plain that if the pressure remains constant, the height of this column under the influence of no temperature above 0° C., will be less than is expressed by the above formula. This amount of shortening will be expressed by the portion of the formula $(b \times 0.00018.t°)$, therefore, the correction for temperatures above 0° C. lessens the length of the observed column, whereas, for temperatures below 0° C., they increase its length. The corrections for temperatures above zero are made by this formula:

$$b_0 = \frac{b_t}{1 + (0.00018 \times t°)}$$

b_0 = Height of mercurial column at 0° C.

$b_{t°}$ = Height of mercurial column at existing temperature as shown by attached thermometer.

$t°$ = temperature indicated by attached thermometer.

0.00018 = co-efficient of expansion of mercury.

Example.—Observed height of barometer, 750 m.m.
Temp. of attached thermometer, 20° C.
What should the height of the column be when reduced to 0° C.

$$b_0 = \frac{750}{1 + (0.00018 \times 20)} = 747.3 \text{ m.m.}$$

Strictly speaking, there are several other corrections which should be made before the absolute length of the mercurial column due to atmospheric pressure alone can be determined. These are corrections

for index error of instrument, capacity corrections, and capillarity correction, but for our purposes the reduction to 0° C., as given above, will suffice.

NOTE.—Where the Fahrenheit scale is employed it must be remembered that for each degree on this scale, above 32°, the co-efficient of expansion of mercury is 0.0001001. Also, that the freezing point in this scale is at 32°, and not at 0°, as in the case of the centigrade. We must, therefore, remember in reducing our mercurial column to the normal conditions of temperature, that in the one scale, centigrade, this point is 0°, and in the other, Fahrenheit, it is 32°. In the case of the latter, therefore, 32 must be subtracted from the reading of the attached thermometer. Substituting then these quantities for those found in the formula given we should have

$$b_{32} = \frac{b}{1 + (0.0001001 \times (t - 32))}$$

Moisture in the Atmosphere.—As has been said, the amount of moisture which the air is capable of holding in the form of invisible vapor is dependent upon the temperature of the air and upon the opportunities presented to it for taking up water.

The presence of water in the invisible form of vapor may easily be demonstrated by bringing the air in contact with some body of a much lower temperature. The moisture will become condensed upon the sides of the vessel in the form of visible water; this is the phenomenon known commonly as "sweating" which one sees upon the outside of ice pitchers. It is the condensation of the water-vapor from the air in immediate contact with the vessel.

The air is rarely saturated with moisture, that is, it rarely contains so much in the form of vapor as to render it impossible for a little more to be taken up. A simple experiment will prove this. If in an ordinary room one evaporates a basin of water, there will be but little apparent alteration in the air of the room, still it has taken up in the form of invisible vapor all of the water which was before in the vessel. This water may be recovered by reducing the temperature of the air of the room to a point at which the invisible vapor becomes condensed.

By the addition of water-vapor to dry air the volume of the latter becomes increased. If the weight of the original volume of dry air be known it will now be found that for the same volume the addition of water-vapor has lessened the weight and that this diminution in weight is proportionate to the amount of vapor added.

In other words, dry air is of a much higher specific gravity than moist air.

If three vessels of known weight and of exactly the same volume be filled, the first with absolutely dry air, the second with air in which some moisture is present, and the third with water vapor alone, it will be found that the weight of the contents of No. 1 will be heaviest, that of No. 3 lightest, while No. 2 will occupy a position between the two, its relations to No. 1 or No. 3 being dependent upon the proportion of vapor which is substituted for the dry air.

The ratio between the weights of equal volumes of dry air and of water vapor at the temperature of 10° C. (50° F.), is as 133 to 1; that is to say, at this temperature, dry air is 133 times as heavy as water vapor, volume for volume.

A litre of dry air at 0° C. and 760 m.m. pressure weighs 1.293 grams.

A cubic foot of dry air at 32° F. and 29.922 inches pressure weighs 0.80728 pounds.

When water-vapor mixes with dry air the volume of the latter is augmented; the weight of a cubic foot of dry air at 60° F. is 536.28 grains; and that of a cubic foot of vapor at the same temperature is 5.77 grains; the two together would weigh 542.05 grains, but owing to the increase in volume of the air which the addition of water vapor causes we find a cubic foot of saturated air at 60° F. to weigh only 532.84 grains. From what has been said it is plain that the addition of water-vapor to air renders it lighter, and that this diminution in weight is proportionate to the temperature, for, as said, the higher the temperature of the air the greater the amount of vapor that it can take up.

Tension of Vapor.—Vapor as it exists in the air exerts a force which is also dependent upon temperature. This elastic force, acting in all directions, is known as the tension of the vapor. It is capable of doing work. It will support a column of mercury, the height of which will depend upon the temperature under which the vapor exists. By virtue of this tension vapors have always a tendency to escape or press out from the vessels containing them. If with a properly constructed apparatus a volume of water-vapor be subjected to varying temperatures, it will be seen that the height of the mercurial column which it supports, as shown by the manometer, will rise as the temperature rises, and fall as the temperature falls.

Experiment has shown a certain regularity in this increase of tension with increase of temperature. The following table gives the height of a mercurial column supported by aqueous vapor under different temperatures:

TENSION OF AQUEOUS VAPOR IN m.m. OF MERCURY :

t° C.	m.m.	t° C.	m.m.	t° C.	m.m.	t° C.	m.m.
0	4.6	10	9.1	20	17.4	30	31.5
1	4.9	11	9.8	21	18.5	40	54.9
2	5.3	12	10.4	22	19.6	50	92.0
3	5.7	13	11.1	23	20.9	60	148.9
4	6.1	14	11.9	24	22.2	70	233.3
5	6.5	15	12.7	25	23.5	80	354.9
6	7.0	16	13.5	26	25.0	90	525.5
7	7.5	17	14.4	27	26.5	100	760.0
8	8.0	18	15.3	28	28.1	....	....
9	8.5	19	16.3	29	29.7	....	....

From the table a gradual increase in the tension will be seen to co-exist with a corresponding rise in temperature until the boiling point of water (100° C.) is reached, when it exactly equals the normal pressure of the atmosphere.

Without opening the discussion as to the part played by aqueous vapor in influencing general atmospheric pressure, we may nevertheless see that in closed spaces its presence means the absence of just so much dry air which it displaces, and as dry air is heavier than water vapor, it is easy to see that with an increase in the amount of vapor present in these spaces, we have a corresponding diminution in the specific gravity of the contained air.

Effusion of Gases.—Effusion is the term applied to the passage of a gas from one space into another space occupied by the same gas. It can only occur when the pressure in the one space is greater than that in the other.

In the strictest sense, the term as employed by physicists, refers to the flowing of a gas from an inclosed space into vacuum through a minute aperture not more than 0.013 m.m. in diameter in a very thin plate of metal or glass.

In our studies the term will be employed to express the efflux of gases of different densities through larger openings. The velocity of the efflux of a gas of known density under known pressure into vacuum is expressed by the formula,

$$v = \sqrt{2gh},$$

in which h represents the pressure under which the gas flows expressed in terms of the height of a column of gas which would exert the same pressure as does the effluent gas. Thus, if air under normal pressure flows into vacuum, this pressure is equivalent to that exerted by a

column of air capable of sustaining the weight of a column of mercury 760 m.m. high. As mercury is about 10,500 times as dense as air an equivalent column of air would be 760 × 10,500 = 7,980 meters. The velocity then with which air under ordinary atmospheric pressure would flow into vacuum would be

$$v = \sqrt{2.\ 9.8.\ 7{,}980} = 395.5 \text{ meters per second.}$$

(9.8 meters, or 32 feet, represent the accelerative effect of gravity). This, however, would be only for the first second of time, for after this there would be an accumulation in what had been vacuum, and hence the difference in pressure between the air in the two spaces will gradually diminish. With this diminution in difference a lessening of the velocity of efflux ensues, until finally, when the pressure in both spaces are equal, no movement whatever occurs. If during the efflux the pressure in both spaces be measured at given intervals, and expressed by h. h_1, etc., the velocity of efflux at each of these intervals may be calculated by the formula:

$$v = \sqrt{2.\ g.\ (h - h_1)}$$

h = pressure under which the gas is flowing.

h_1 = accumulating pressure in what was originally vacuum.

In our work the second formula is the one which will be employed in calculating the rate of efflux between gases of different densities. We shall never meet the conditions in which the first may be employed.

As an illustration of its application the following problem may be cited.

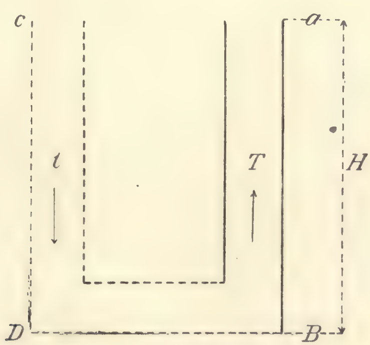

FIG. 3.

Imagine aB to be a vertical canal open above, a chimney for example, of the height H and of equal diameter throughout. So long

as the air in aB is of the same density and specific gravity as the surrounding air no motion occurs. So soon as alterations in the relative densities of the two bodies of air occur, motion begins. Such alterations may be caused by elevation in the temperature of the one body of air over that of the other. Suppose the temperature of the outer air to be lower than that in the canal (T) and imagine aB to be continued into a canal cD thus forming the imaginary U tube, aB cD. Now the imaginary arm of the tube represented by cD is assumed to be of the same size throughout as is aB. It differs from aB only in the temperature of the air contained in it, which is lower and will be represented by $t°$. We shall now have a U tube in the one arm of which the air is of a higher specific gravity than that in the other arm. For, as we have shown, with an increase in the temperature of air there is a corresponding decrease in its density and specific gravity. In the case in point there must, of necessity, be an effort at the establishment of equilibrium and the denser air in the arm cD at the temperature $t°$ will sink at the same rate that the rarer, lighter air in the arm aB at the temperature $T°$ ascends.

It is here that we must employ the formula, $v = \sqrt{2\,g\,h}$ for obtaining the height $\left(h = \frac{v^2}{2\,g}\right)$ through which the bodies of air fall. The distance through which the denser air in cD falls is the difference between the height of an imaginary column of air of the weight of cD at the temperature T, and the actual measured height of the tube aB, as expressed by H. In order to obtain this difference it is necessary to convert the two columns of air in aB and cD into columns of equal weight, but of densities expressed at the temperature of 0° C. They will, therefore, be of different height. For as the diameters of the tube or chimney aB and the imaginary chimney cD are constant, the alterations in volume which will result, when their air is reduced to the condition of 0° C., must have its expression in the lessening of the height of each column.

The height of aB at $T°$ temperature, when reduced to 0°, is

$$\frac{H}{1 + \alpha.\,T}$$

and that of cD at the temperature $t°$ is

$$\frac{H}{1 + \alpha.\,t}$$

h_0, the height of the pressing column of air reduced to 0° C, is then

$$h_0 = \frac{H}{1 + \alpha.\,t} - \frac{H}{1 + \alpha.\,T}$$

If now it is desired to convert this column of air into one of equal weight, but of the higher temperature T, then will its height h be expressed by $h = h_0 \ (1 + \alpha.\ T)$, or substituting the value of h_0 just found, we shall have

$$h = (1 + \alpha.\ T) \left(\frac{1}{1 + \alpha\, t} - \frac{1}{1 + \alpha\, T}\right) H$$

and since $h = \frac{v^2}{2\,g}$ then

$$\frac{v^2}{2\,g} = (1 + \alpha\ T) \left(\frac{1}{1 + \alpha.\, t} - \frac{1}{1 + \alpha\, T}\right) H.$$

$$\text{and } v = \sqrt{2g\,.\ (1 + \alpha\ T) \left(\frac{1}{1 + \alpha\, t} - \frac{1}{1 + \alpha\, T}\right) H.}$$

Throughout this formula, which may be employed in calculating the rate of flow or draught with chimneys, etc., it will be remembered that

v = velocity of flow.

g = accelerating effect of gravity, 9.8 meters per second.

T = higher temperature in chimney.

t = lower temperature of outside air.

H = height of chimney.

α = co-efficient of expansion of air.

It must be borne in mind that the formula as it stands is strictly theoretical, and could only be employed in practice after certain corrections for friction, curves and alterations in calibre of the tubes had been made. These corrections will be introduced in a later chapter

In addition to the movement set up in connecting bodies of air of different densities, we shall also find a constant tendency toward effusion between such bodies, even though they may be apparently separated the one from the other. In this case, the current is not set in motion through free openings in tubes or shafts, as in the case cited, but through the capillary tubes or pores in the separating medium.

If two bodies of air of different temperatures are separated the one from the other by a permeable partition, there is a constant tendency toward the establishment of a current from the cooler, denser, toward the warmer, rarer body, and *vice versa*.

By a careful study of this phenomenon, it is seen that if the separating medium be an enclosure with six sides, a hollow cube, for instance, that these currents will be established according to certain definite and constant laws. It is seen that on the vertical sides of

the cube the direction of the current is not the same for each and every point.

Supposing the cube to contain the warmer, less dense volume of air, it will be seen that the direction of the current becomes reversed as we pass from the highest to the lowest levels of each lateral wall. At the highest elevation the stream will be most pronounced from within outward, gradually diminishing as we near the center, where the so-called neutral zone, through which there is no appreciable efflux, is found. Passing below this, a current, the reverse of the outward flow, is met. It increases in intensity in practically the same progression as the outward current diminished until we reach the lowest level where it is greatest, and will be found to correspond in intensity (in homogeneous partitions) with the most elevated of the outgoing streams.

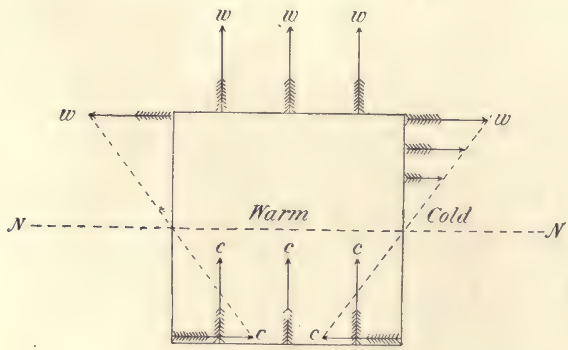

FIG. 4.

NN = neutral zone. *w* = warm outflowing air. *c* = cold inflowing air.

Figure 4 represents the phenomenon diagrammatically. The figure is a vertical section through such a cube, the six sides of which are of homogeneous material and the air within the cube of higher temperature than that surrounding it.

From the figure it may be seen that under the conditions cited the strongest expressions of out and inflow are represented by the arrows *w* and *c* at the highest and lowest levels, respectively, of the lateral sides of the cube; and a gradual diminution toward the central, "neutral zone" occurs in both cases.

Over the horizontal faces of the cube, top and bottom, the intensity of efflux as represented by the arrows for the cold air from without in, and for the warm from within out, is everywhere equal.

What now is the explanation of this phenemenon? As has been said, the tendency for warmed air is to expand and escape from the vessel containing it. It has also been said that warm air is of a lower specific gravity than cold air—it has therefore a tendency to ascend. Now for the case under consideration we find that the point of greatest density for both the warmed air within and the cold air without our cube is at the floor level and that of least density at the level of the ceiling. In both cases however, the cold outer air is denser than the warm inner air and consequently there should be a tendency over the whole outer side of the separating partition for the colder air to rush in toward the warmer air; but this tendency is overbalanced in part by the low specific gravity and tension which the inner air has acquired by its elevation in temperature; so that it presses outward on all sides of the vessel containing it.

Our body of warmed air of low specific gravity surrounded by the mass of cooler air of greater density has been aptly likened to a mass of solid matter immersed in a fluid of higher specific gravity—a block of wood immersed in water, for example. It experiences its greatest pressure from the surrounding denser fluid at its point of lowest level, which pressure diminishes as we approach the point of highest level. In the case then of our warmed air enclosed in a space with upper and lower openings—a room, for example—we see over the floor and lower parts of each side the pressure from the denser, cooler air is inward, toward the warmer body of lower specific gravity. As the denser air enters through the openings into the cube (the source of heat in the cube remaining constant) it in turn becomes heated and ascends. Some of the warmed air that was in the cube must in turn be pressed out and by proper means we find that just at the same rate as the cooler, denser air enters at the bottom and lower parts of the sides, the warmer, rarer air, of less specific gravity and higher tension, is forced out through the ceiling and upper parts of the sides of the cube.

By the employment of a delicate differential manometer we shall find that the point of greatest pressure in the outer column of cold air is at the floor level of our cube, and that the pressure gradually diminishes as we approach the ceiling. For the warm inner air the point of least tension will be found at the floor, and that of the highest tension at the ceiling.

The result of these conditions is the establishment of two currents, as shown in Fig. 4—a cold inflowing current, greatest in intensity at the floor level and diminishing as we ascend, and a warm outflowing

current, greatest in intensity at the ceiling level and diminishing as we descend.

Figure 5 also illustrates what takes place under these conditions.

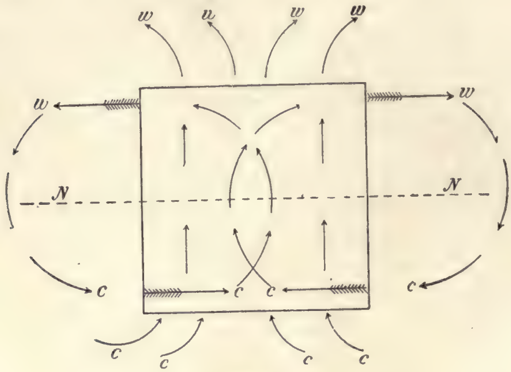

FIG. 5.

Such an exchange between bodies of air of different temperatures is constantly in progress. It is what occurs in the so-called "natural ventilation," and it forms the fundamental principle upon which nearly all artificial contrivances for the renewal of air in apartments are based.

In the chapter upon forces concerned in ventilation reference will again be made to this subject in its practical application.

NOTE.—This phenomenon may be satisfactorily demonstrated by the employment of a very inexpensive model. A wooden frame of about 8 feet high by 4 feet by 2 feet, covered with ordinary muslin, has on its long face two openings, each 4″ x 6″ in size—the one just above the floor, the other just below the ceiling—these openings to be closed by loosely swinging paper flaps. If now the interior of our model be heated by a Bunsen burner, or lamp of any description, it will be seen that the lower flap will be deflected inward and the upper outward. A series of flaps down the median line, each situated about 4 inches from the one above it, will also demonstrate the diminution in the intensity of each stream as we approach the median line, "neutral zone."

CHAPTER IV.

CARBONIC ACID.

THE proportion of carbonic acid in the atmosphere is considered to be of such biological and sanitary importance that it is deemed advisable to devote a separate chapter to the subject.

In the studies of the chemistry of the air the points that have been considered worthy of determination, in so far at least as the proportion of carbonic acid is concerned, are: Is it possible to speak of a constant mean proportion of this gas for all places on the earth's surface? Does the air over the land differ in the proportion of this gas contained in it from that over the sea? Is the proportion of carbonic acid in the air of cities greater than that in the air of the open fields of the country? Does the proportion of this gas remain constant for the same place under varying conditions—for day and night; for winds from all directions; for fair and foul weather, etc.? Is the proportion of this gas seen to differ at different altitudes? And is the relatively lower proportion of CO_2 in the air, which experiments of to-day reveal, due to improvements in methods or to differences in the rate of production?

The experiments which have been made with the object of answering these questions have been many in number, and have not all been made by the same methods of work, or by the same individuals. A glance over the history of the subject will suffice to show that the results which have been obtained in recent years are on the whole much lower than those obtained by the earlier experimenters. It seems reasonable to attribute these differences rather to increased accuracy in the methods of analysis than to any diminution in the proportion of this gas in the air, for during the ninety years which have elapsed since de Saussure first published the results of his quantitative analysis of the air, but little change in the natural and artificial processes incidental to life which would tend to lessen the proportion of this gas existing in the air, could have occurred.

In the accompanying table (Table I.) will be found, grouped together in the order in which they were published, the results of the

TABLE I.

Volumes of Carbonic Acid in 10,000 Vols. of Air as Found by Different Observers and at Different Places since the Time of de Saussure.

Observer.	Place.	Date.	Vols. of CO_2 in 10,000 Vols. of Air.
De Saussure	Geneva	1809–15	6.000
Thenard	Paris	1813	3.910
De Saussure	Chambeisy	1816–28	4.900
De Saussure	Chambeisy	1827–30	4.100
Brunner	Bern	1832	4.180
Tissandier	Balloon ascension, alt. 2920 ft.	....	2.140
	" " " 3281 ft.	....	3.000
Boussingault	Paris	1839–40	4.000
Marchand	Halle	1845	3.100
Levy	Atlantic Ocean	1847	4.600
A. & H. Schlagentweit.	Käruthen	1853	5.800
	Switzerland	....	9.000
Gilm	Innsbruck	1857	4.150
Pettenkofer	Munich	1858	4.500
Regnault	Paris	1859	4.000–6.000
Schulze	Rostock	1863–64	3.640
Schulze	Rostock	1868–71	2.920
Thorpe	S. America (at Para)	1866	3.280
Thorpe	Irish Sea and Atlantic Ocean.	1865–66	3.000
Storer and Pearson	Boston	1871	3.854
Hill	Cambridge	1871	3.390
Smith	London	1872	3.490
Heuneberg	Weende	1872	3.200
Risler	Calives	1872–73	3.000
Truchot	Clermont-Ferrand	1873	3.130
Truchot	Puy de Dôme (alt. 4,774 ft.)	....	2.030
Truchot	Pic de Sancy (alt. 6,181 ft.)	....	1.720
Reiset	Montsouris	1873–80	2.962
Farsky	Tabor (Bohemia)	1874–75	3.430
Fittbogen and Haesselbarth	Dwhne	1874–75	3.200
Muir	Andrassan (Scotland)	1876	3.640
Claesson	Lund	1876	2.800
Hesse	Munich	1877	3.300
Levy	Montsouris	1877–83	3.000
Wolffhügel	Munich	1879	3.760
Macagno	Palermo	1879	3.900
Armstrong	Grasmere	1880	2.960
Fodor	Budapest	1881	3.890
Fodor	Klausenbürg	....	3.800
Müntz & Aubin	Orange Bay (Cape Horn)	1881–84	2.560
Müntz & Aubin	S. Atlantic Ocean	....	2.680
Dumas	Paris	1882	2.800–3.500
Heine	Giessen	1882	2.620
Reichardt	Jena	1882–84	3.000
Ebermeyer	Bavarian Highlands	1883–84	3.200
Blochmann	Königsberg	1885	3.000
Spring and Roland	Lüttich	1885	3.300

TABLE I. (*Continued.*)

Observer.	Place.	Date.	Vols of CO_2 in 10,000 Vols. of Air.
Carnelley and Mackey.	Dundee	1886	3.175
Carnelley and Mackey.	Perth	1886	3.100
Feldtz	Dorpat	1887	2.660
Carnelley and Wilson.	Scotch Moorlands	1887–88	3.90
Uffelmann	Rostock	1888	3 51
Heimann	Dorpat	1888	2.690
Frey	Dorpat	1889	2.620
Roster	Florence	1889	3.140
Abbott	Baltimore	1889	3.750

more prominent experiments which have been made from the time of de Saussure to the present. And, as stated, the tendency throughout the later experiments is toward a smaller mean proportion of atmospheric carbonic acid than was found by the earlier observers. It will be seen, moreover, that since the introduction by von Pettenkofer in 1858, of the method of analysis which bears his name, that the results of these experiments are on an average much lower than the mean of those observations published prior to that date, and that the range of fluctuation in the results has been considerably diminished.

By dividing the experiments which have been made since the experiments of de Saussure into groups and taking their mean, a better idea of the diminution in the results obtained may be formed. In dealing with the series of results in this way, it has been deemed advisable to omit from the results from which the means are calculated the analyses of Tissandier and those of Truchot which were made at high altitudes, likewise the experiments of Kidder in Washington, because of their exceptionally high results, which must certainly have arisen from some strictly local causes.

Period I.—From de Saussure to Pettenkofer, inclusive,	=	4.852
Period II.—From Regnault to Reiset, inclusive,	=	3.392
Period III.—From Farsky to Reichardt, inclusive,	=	3.218
Period IV.—From Ebermeyer to Roster, inclusive,	=	3.118
Mean since 1858 (introduction of Pettenkofer's method),	=	3.243

While it is probable that certain local conditions may play a part in causing differences in the proportion of carbonic acid found at different places, still it must be borne in mind that an equally potent factor in producing this difference in results is the method which is

employed in making the analyses. Prior to the introduction by von Pettenkofer, in 1858, of the method which bears his name and which is now so generally practised, many of the analyses were conducted in a way that could hardly lay claim to a very high degree of accuracy. For example, Levy's experiments in 1847 were made by passing a measured quantity of air through glass tubes, containing pumice stone, which had been soaked in potassium hydroxide. The CO_2 was fixed by the alkaline base. These tubes were then sealed, and after 18 to 20 months their contents were subjected to the action of acid; this liberated the carbonic acid which was collected, and its volume measured eudiometrically by the method of Regnault. In speaking of the possible error through the employment of this method, Dr. Frankland (Jour. Chem. Soc., London, Vol. VI., p. 199) says: "A variation in volume which would be indicated by only a small numerical expression in the Regnault-Reiset apparatus would be considerable had it appeared in the more exact analytical methods of gas analysis as recommended by Bunsen." Moreover, Levy's analyses were made a long time after the air had been passed through the tubes; in some instances as much as 18 to 20 months having expired, and though he had convinced himself that during this time air confined in glass tubes underwent no appreciable change, still Regnault has subsequently demonstrated the error of this opinion. Regnault has shown that an accurate estimate of the proportion of carbonic acid originally present in air which had been contained in glass tubes for a long time cannot be made because of the absorption of gases by the glass.

Such sources of error must have existed in many of the analyses which were made prior to our more exact methods of to-day, and it is only reasonable to conclude that the grounds for the smaller mean proportion of CO_2 now found in the air can, at least in part, be attributed to correction of these errors.

By tabulating the results of analyses which have been made upon the air of cities, it will be seen that, on the whole, the proportion of carbonic acid is higher than in the air of the country, and that its range of variation is much greater. These differences are doubtless due in most part to strictly local conditions. In cities the greater activity of life, the excess of artificial processes of oxidation, the crowding together of a larger number of human beings and animals into small spaces, and the interference with free circulation and diffusion of air would lead one *a priori* to anticipate the presence of a larger proportion of this gas in the air than would be found in the air of localities in which these sources of production were diminished or absent. Moreover, in cities

the influence of plant life in diminishing the proportion of this gas in the air is very much less than in the rural districts.

In the accompanying tables are compared the results of a number of analyses which have been made upon the air of cities and that of the country.

TABLE II.

CO_2 in the Atmosphere—Analyses of Air in Cities.

Observer.	Place.	CO_2 in 10,000 Vols. of Air.
Angus Smith, 1872..	Geneva	4.68
" " "	Chambeisy	4.60
" " "	Madrid	5.16
" " "	Streets of Manchester	4.03
" " "	" " London	3.80
" " "	" " " N. and N. W. winds	4.44
" " "	" " " S. " S.W. "	4.39
" " "	" " " E. " S.E. "	4.75
" " "	" " " W. "	4.12
" " "	At different towns in Scotland (average)	3.36
" " "	Glasgow	5.02
Boussingault	Paris	4.00
Wolffhügel	Munich	3.76
Macagno	Palermo	3.60
Reiset	Paris	3.03
Fodor	Klausenburg	3.80
Fodor	Budapest	3.89
Farsky	Tabor	3.43
Spring and Roland..	Lüttich	3.33
Hesse	Munich	3.30
Blochmann	Königsberg	3.00
Schulze	Rostock	2.92
Uffelmann	Rostock (average of 420 analyses)	3.51
Roster	Florence	3.14
Thenard	Paris	3.91
De Saussure	Geneva	4.15
Abbott	Baltimore (result of 19 analyses made at the same place on the lawn of the Johns Hopkins Hospital during December, 1889)	3.75
Storer and Pearson..	Boston—Mean of 21 analyses made in streets.	3.854
Hill	Cambridge, Mass	3.390
Heimann	Dorpat—Mean of 601 analyses from June to September, 1888	2.69
Feldtz	Dorpat—Mean for February, March, April, May, 1887	2.66
Frey	Dorpat—Mean from 556 analyses	2.62

Kidder (extract from the Report of the Surgeon-General of the Navy, for 1880, Washington, Government Printing Office, 1882), whose observations were made upon the air of the streets of Washington, D. C., obtained as a mean of 96 analyses, the remarkably high proportion

of 7.66 parts of carbonic acid in 10,000 parts of air. Though Kidder is known to be a careful observer, still his results are of such an unusual character and differ so materially from those obtained by other observers at the same place, that it seems probable there was some special undiscovered source of error in his work which would make it undesirable to include his results in the table of comparisons that we are presenting.

TABLE III.

Analyses by Storer & Pearson, Showing the Proportion of Carbonic Acid in the Air from the Streets of Boston. Mass. Pettenkofer's Method.

Date 1870.	Time of Day.	Temperature of Air—Centigrade.	Barometer Inches.	Locality.	Vols of CO_2 in 10,000 Vols of Air.	Remarks.
March 17	11.00 A. M.	3.5°	29.330	Newbury St., near Institute of Technology.	4.560	Cloudy. Wind, N.W.
April 1	8.45 "	9.0	30.372	"	3.194	Clear. Wind, N. E.
" 1	8.45 "	9.0	30.372	"	3.894	" " "
" 8	9.40 "	13.0	30.134	"	3.988	" " "
" 8	9.40 "	13.0	30.134	"	4.449	" " "
" 8	9.40 "	13.0	30.134	"	4.218	" " "
" 13	11.00 "	14.0	30.000	"	3.798	Clear. Wind, N.
" 13	11.00 "	14.0	30.000	"	4.435	" " "
" 14	2.35 P. M.	25.0	30.016	"	4.230	Clear. Wind, S. W.
" 14	2.35 "	25.0	30.016	"	4.292	" " "
" 28	2.20 "	28.0	29.872	"	4.999	Cloudy. Wind, S.W.
" 28	2.20 "	28.0	29.872	"	4.903	" " "
May 3	8.30 "	14.0	29.936	Park Street, near Tremont	4.493	Clear. Wind, N.
" 12	2.45 "	22.0	29.852	Newbury Street........	3.394	After storm, light clouds. Wind, S. W.
" 12	2.45 "	22.0	29.852	"	3.561	"
" 17	10.45 A. M.	14.0	30.170	Public Garden.......	2.905	Cloudy. Wind, N.E.
" 18	4.05 P. M.	22.0	30.336	"	3.563	Clear. Wind, S. W.
" 19	10.50 A. M.	25.0	30.244	"	2.969	" " "
" 30	3.40 P. M.	20.0	30.264	"	2.586	" " S. E.
" 18	3.15 "	20.5	30.336	Cupola of State House. ...	3.139	" " S. W.
" 19	1.30 "	28.0	30.212	Clarendon Pl., nr. Berkley St....................	3.371	" " "
				Mean of 21 Observations,	3.854	

During December of 1888 and April of 1890, a few scattered analyses of the air over the lawn of the Johns Hopkins Hospital, at Baltimore, were made by Abbott, and resulted in a mean of 3.750 parts of carbonic acid per 10,000 parts of air.

Of the nineteen analyses made at the same spot, about 3 feet above the surface of the soil, under varying conditions of wind and weather, the lowest amount found was 3.300 parts and the highest was 5.700 parts in 10,000. Upon what conditions the latter figures depend it is impossible to say. It was supposed that the wind blowing from the

TABLE IV.

Proportion of Carbonic Acid in the Air of Cambridge, Mass., Pettenkofer's Method.*

Date.	Time of Day.	Temp. of Air. Cent.	Barometer Inches.	Locality.	Vols. of CO_2 in 10,000 Vols. Air.	Remarks.
1870. Dec. 29..	4.00 P. M.	− 5°	29.457	....	3.75	Cloudy. Snow during previous 24 h.
" 30..	12.00 M.	− 9°	29.973	....	3.76	Fair. Wind, S.W.
" 30	4.00 P. M	− 7°	29.973	....	3.08	Cloudy. " S.
" 31..	11 00 A M.	+ 3°	29.665	....	3.44	Fair. " S.W.
" 31..	2.00 P. M.	+ 6°	29.626	....	3.64	" S.
1871. Jan. 2..	3.30 P. M.	+ 4°	29.649	College Yard, 20 Feet N. of Boylston Hall.	3.43	Cloudy. " S.W.
" 3.	11.00 A. M.	0°	30.063	....	3.10	Clear. " "
" 3..	2.30 P. M.	− 1°	30.000	....	3.11	
" 4..	11.00 A. M.	− 5°	30.240	....	3.31	" " W.
" 4..	3.30 P. M.	− 5°	30.264	....	3 32	
" 5..	9.co A. M.	− 3°	30 158	....	3.33	Cloudy. " S.E.
				Mean of 11 Observations...	3.39	

* These analyses were made by H. B. Hill, Assistant in Chemistry, Harvard University.

boiler vaults toward the spot at which the analyses were in progress, might have caused the excessive amount of gas, by blowing the products of combustion from the furnaces to this point, but as no constant relations between winds from this quarter and the results of analyses could be established, this explanation for the high proportions of the gas, had in part, to be abandoned. On December 23d, however, at a point a little nearer (about 50 yards) to the furnaces, a distinct odor of sulphur dioxide was noticed in the air, and an analysis made immediately at this point, resulted in 5.100 parts of carbonic acid in 10,000 air. It was this result that suggested the probable explanation for some

of the high figures; but as stated, no constant connection between winds from this quarter and excessive proportions of carbonic acid in the air could be established.

As a portion of this lawn is "made ground," analyses of the soil air were made and resulted in showing a proportion of carbonic acid at 10 inches below the surface of the soil of 53.1 parts in 10,000 of air, and at 5 feet of 120.2 parts in 10,000 of air, so that the irregular diffusion of this gas from the soil into the lower strata of the atmosphere is most probably the reason for the variations found, and in the

TABLE V.

CO_2 in the Air of Open Fields, Forests and Mountains.

Observer.	Place.	CO_2 in 10,000.
Reiset	Open fields near Dieppe	2.942
	In a young forest	2.917
	At the same time over the open fields (exp. station)	2.902
	Over a blossoming clover field	2.898
	At the same time over the open fields (exp. station)	2.915
	Over a barley field	2.829
	At same time over the open fields (exp. station)	2.933
	In a field near a sheep herd (300 head)	3.178
Davy & Levy	Montsouris	3.020
	1876	2.590
	1877	2.840
	1878	3.450
	1879	3.290
	1880	2.700
Armstrong	Grasmere (Westmoreland)	2.960
Müntz & Aubin	Open field	2.880
Uffelmann	Air of country near Rostock	2.79–3.66
Ebermeyer	Bavarian Highlands	3.20

light of Fodor's experiments made at Budapest, I am inclined to accept this latter suggestion as the explanation of the inconstancies in the results. Fodor found that the variations in the amount of carbonic acid in the air for about 6 feet above the surface of the soil were plainly due to diffusion of this gas from the soil.

Saussure,[1] in 1830, clearly demonstrated that the presence of large bodies of water has a very appreciable influence upon the proportion of carbonic acid in the atmosphere above them.

[1] Saussure. Ann. Chim. and Phys., XLIV., 1830.

From simultaneous analyses made of the air from the center of Lake Geneva and over the land near the bank, he found the average proportion of carbonic acid to be a little less in the air from over the lake than in that from over the land near the lake.

Vogel[1] had likewise obtained similar results, demonstrating the abstraction of this gas from the air by bodies of water.

Krüger[2] failed to detect its presence in the air over the Baltic.

TABLE VI.

Comparison Between the Amount of Free Carbonic Acid Found in the Air of Cities and That of the Country.

Analyst.	Place at which Analyses were made.	CO_2 in 10,000	Difference.
de Saussure, 1830, 32 analyses.....	Chambery, near Geneva.......... Geneva...........................	4.37 4.68	0.31
Boussingault.....	St. Cloud.... .... Paris.......	4.13 4.14	0.01
Boussingault & Levy, Sept. and Oct., 1844, 2 ex-experiments....	Andilly (near Montmorency)...... Paris.....	2.98 3.17	0.19
Smith............	Manchester (fields about).......... Manchester (in city)....	3.69 4.42	0.73
Luna.......	Madrid (outside the city).......... Madrid (in the city)...............	4.50 5.20	0.70
Smith.......	London (in open parks) .... London (in the streets)............	3.01 3.41	0.40
Uffelmann........	Rostock (in city) 3.10 to 4.04, mean Rostock (in country) 2.79 to 3.66, mean..................	3.57 3 23	0.34

The conclusions which were drawn from these experiments, were to the effect that the air over the open sea would be found to be free from CO_2.

Emmet and Dalton,[3] in 1836, showed conclusively that carbonic acid is present in the air of mid-ocean.

Levy,[4] at the request of the French Academy, in 1848, made a series of analyses of the air over the sea. His work, which

[1]Vogel. Ann. Phil. N. S., VI., 75.
[2]Krüger. Schw. Jour., XXXV., 379.
[3]Emmet and Dalton. Phil. Mag., XI., 225.
[4]Annales de Chim. et. d. Phys. Serie 3, Tome XXXIV., 5.

was done while on a voyage from Havre to Santa Marta, resulted as follows:

TABLE VII.

Date.	Condition of Weather.	Latitude, N.	Long. W. of Paris.	CO_2 in 10,000, Each the Mean of 3 Analyses.
		° ′	° ′	
Dec. 1, 1847	Cloudy	47–30	10–5	4.881
" 4, "	Cloudless	47–00	13–0	3.388
" 8, "	Few Clouds	35–40	20–35	5.497
" 17, "	Cloudless	22–5	39–0	5.771
" 18, "	"	21–45	41–3	3 346
" 18, "	Few Clouds	21–9	42–25	5 420
" 19, "	Cloudless	20–35	43–35	3.388
" 26, "	"	15–49	64–28	5.288
" 28, "	"	14–6	70–4	5 093
" 30, "	"	12–5	76–0	5 143
" 31, "	"	....	....	3.767
			Mean	4.630

In addition to the above Levy found the day air to be much richer in CO_2 than air taken at the same place at night. For example, he found:

Mean of 7 day experiments, 5.299 CO_2 in 10,000.
Mean of 4 night experiments, 3.459

1.840

The means of analyses made by Levy at about midway between the continents at the center of the ocean, and at the same hours in the night and day, were as follows:

Carbonic acid at 3 A. M. = 3.346
" " " 3 P. M. = 5.420

2 074

He attributes this phenomenon to the dissolution and admixture with the atmosphere, of the gas from the surface of the sea in consequence of the warming of the water by the sun's rays.

From Levy's experiments it would seem that the sea air is richer in CO_2 than that over the continents, and that the increase in the proportion of this gas was due to the warming action of the sun upon the superficial layers of the ocean, from which the acid is disengaged.

This conclusion is contrary to that arrived at by Krüger,[1] who believed the sea to abstract CO_2 from the atmosphere.

[1](Schw. J., XXXV., 379), and Vogel (Ann. Phil. N. S., VI., 75).

They differ very materially also from those arrived at by Thorpe and by Müntz & Aubin, the result of whose work appears in the following tables.

In considering the results given by Levy, which are much higher than those obtained by subsequent observers, the criticism of Dr. Frankland upon the methods employed by Levy, to which reference has already been made, must not be lost sight of.

Thorpe,[1] during 1865-66, conducted a series of analyses upon the atmosphere of the sea. His first series of experiments, the details of

TABLE VIII.

Vols. CO_2 in 10,000 Vols. Air Over Irish Sea. Pettenkofer's Method.

Date.	Bar.	Temp. of Air. Dry.	Temp. of Air. Wet.	Temp. of Sea.	Wind, Etc.	Carbonic Acid. 1st Exp	Carbonic Acid. 2d Exp.	
1865. Aug. 4...	762.5	16.4	11.1	16.0	N.W.xW., very light.	2.66	3.07	Day very fine and clear.
" 5...	762.0	13.9	12.9	15.0	S.W.xS. light breeze.	2.92	3.05	
" 5..	761.2	16.1	14.4	15.0	S.W.xS.	3.08	3.21	
" 7...	753.4	14.2	13.3	15.0	S.W.xS., light.	3.30	3.22	Baryta-water exposed 3 hours
" 7...	757.5	17.2	15.1	15.6	N.W., "	3.20	3.15	Sunny—very fine.
" 8...	760.2	13.6	12.2	15.0	N. N.W., moderate.	3.06	3.19	
" 8..	761.0	18.3	13.1	16.0	N. N.W., light breeze.	3.32	3.02	Fine and sunny.
" 9..	758.7	13.3	12.2	15.0	S.W.xW., " "	2.93	3.10	
" 9...	756.4	......	......	15.0	S.xW., moderate.	3.09	3.23	Rain.
" 10...	249.3	15.0	11.9	14.5	S.xW., fresh.	3.11	3.11	Very wet, rain all day.
" 12...	750.5	13.4	11.9	14.5	S.W.xW., strong.	3.09	3.10	Windy. Rain for 11th to 16th.
" 16..	752.3	14.7	12.8	15.0	N.W.xW., light.	2.93	2.95	
" 17...	753.1	13.9	12.8	15.0	W. S.W., fresh.	3.12	2.94	Baryta-water exposed 6 hours.

Hours of observation, 4 A. M., 4 P. M. Thorpe's Table.

which will be found in Table VIII., were made upon the air over the Irish Sea, at a point nearly equally distant from the coasts of England, Ireland and Scotland. As a mean of twenty-six analyses, he found that carbonic acid was present in the air in the proportion of 3.082 vols. in 10,000 vols. of air.

His experiments upon the air of the Atlantic gave, as a mean result of fifty-one experiments, the proportion of 2.953 vols. CO_2 in 10,000 vols. of air.

[1] Thorpe—Mem. Lit. Phil. Soc. (3) Vol. IV.
Thorpe—Jour. Chem. Soc. London, 1867, Vol. XX., p. 189.

TABLE IX.

Vols. of CO_2 in 10,000 *Vols. of Air Over the Atlantic Ocean. Determined by Pettenkofer's Method.*

Date.	Hour.	Ship's Position. Lat.	Ship's Position. Long.	Bar. m.m.	Temp. of Air. Dry.	Temp. of Air. Wet	Temp. of Sea.	Wind.	Carbonic Acid. 1st Exp.	Carbonic Acid. 2d Exp.	
1866.											
Feb. 26..	11.38 P.M.	30°12′ N.	16°32′ W	770.0	15.5	13.0	17.7	N.W.xW. Gentle breeze.	2.90	2.93	200 miles S. of Madeira. Weather fine.
" 27 .	5 24 A.M.	28°43′ N.	17°45′ W	761.5	16.2	13.0	17.0	W. N.W. Moderate.	2.66	2.83	Off Palma, Canaries Cloudy.
" 27..	3.50 P.M.	27°47′ N.	18°00′ W	758 0	17.6	16.0	19.0	W.xS. Squally.	2.83	2.87	Off Ferro, Canaries. Cloudy.
" 28..	3.19 P.M.	26°01′ N.	19°09′ W	760.1	18.5	17.5	19.2	" "	2.97	2.84	Rain.
Mar. 2..	3.40 P.M.	21°30′ N.	23°11′ W	767.1	22.8	17 9	21.7	N. Very light.	3.02	3 06	130 miles S. of the tropic. Very fine.
" 3..	5.15 A.M.	20°15′ N.	24°09′ W	766.0	19.6	18.0		S. "	2.97	2.91	Sea calm. Very phosphorescent.
" 3..	3.00 P.M.	19°17′ N.	24°57′ W	765.0	26.0	21 0	22.0	Variable; light.	3.04	3.12	Calm. Baryta-water exposed 5 hours.
" 5..	4.40 A.M.	15°32′ N.	27°46′ W	764.5	21.2	21.0	22.0	N.E. Gentle breeze.	3.13	3.36	Cloudy. Sea phosphorescent.
" 5..	3.10 P.M.	14°32′ N.	28°26′ W	767.2	26.1	23.6	22.5	S.W. Light and variable.	2 98	2.94	Fine and clear.
" 5..	" "	"	"	"	"	"	"	" " "	3.07	2.96	Exposed 3 hours before titration.
" 6..	4.45 A.M.	13°12′ N.	29°21′ W	767.1	21.8	21.7	22.5	Variable; light breeze.	2.83	2.82	Dark; cloudy. Sea phosphorescent.
" 6..	" "	"	"	"	"	"	"	" " "	2 96	2.91	Baryta-water exposed 2½ hours.
" 6..	5.10 A.M.	11°59′ N.	30°12′ W	764.5	23.5	21.1	23.5	Winds northerly; gentle.	...	....	
" 7..	" "	10°40′ N.	31°03′ W	766.5	23.3	20.0	22.5	N.E.xE. Gentle.	2 97	2.93	Cloudy. Midway between Africa and America.
" 7..	" "	"	"	"	"	...	"	" "	2.99	....	
" 7..	2.35 P.M	9°50′ N.	31°39′ W	766.0	24.2	21.7	24.5	E. "	2.88	2.90	Cloudy.
" 7..	" "	"	"	"	"	"	"	" "	2.78	2.91	
" 8..	5.35 A.M.	7°34′ N.	32°37″ W	766.5	24.2	21.1	24.5	S.E. Fine breeze.	2.74	2.89	Daybreak. Sea phosphorescent during former part of night.
" 8 .	" "	"	"	"	"	"	"	" " "	2.71	2.69	
" 8..	3.15 P M.	6°48′ N.	33°03′ W	760.1	25.6	22.8	25.5	E. N.E " "	....	....	Cloudy.
" 12..	7.45 P.M.	3°12′ S.	38°12′ W	762.5	29.5	26.1	27.2	Light air.	3.09	3.01	Calm. 40 miles from Caera.
" 12..	" "	"	"	"	"	...	"	" "	3.02	3.12	
" 13..	3.10 P.M.	3°43′ S.	38°34′ W	761.3	28.0	26.0	29.0	N.E. Gentle breeze.	3 06	2.98	Off Caen. Very heavy rain before experiment.
July 16..	3.16 P.M.	15°14′ N.	26°13′ W	763.5	26.2	22.8	24.5	N. Light breeze.	2.94	..	Baryta-water in all following experiments titrated with hydrochloric acid solution.
" 17..	8.00 P.M.	18°21′ N	24°25′ W	764 0	23.9	22.5	23.0	E.xN. " "	....		
" 18..	3.00 P.M.	20°09′ N.	23°48′ W	764.5	23.6	22.7	23.0	N.E.xE. Moderate.	3.05	....	
" 18..	6.40 P.M.	20°28′ N.	23°36′ W	765.0	24.3	22.8	22.5	N.E. "	3.05	..	Cloudy.
" 19..	3.15 P.M.	22°25′ N.	22°45′ W	766.4	25.9	22.8	22.5	N.E.xE. Brisk.	3.13	.	Fine and clear.
" 19	9.00 P.M.	22°50′ N.	22°28′ W	767.5	24.3	22.5	22.0	N.E Fresh.	3.09	....	
" 20..	11.15 A M.	23°43′ N.	21°37′ W	770.0	26.1	22.8	22 2	N.ExE. Moderate.	2.90	...	Fine.
" 21..	9.00 P.M	26°19′ N.	19°40′ W	770 0	23 4	20.1	21.2	" "	3.04	..	180 miles S. W. of Ferro, Canaries.
" 24..	7.30 A M.	32°26′ N.	14°38′ W	770.0	23.3	20.6	22.0	N. Light air.	3.00	...	Calm and sunny.
" 25..	10.45 A.M.	33°56′ N.	13°05′ W	773.5	23.5	...	21.2	N.E. Gentle breeze.	2.97	. .	Clear.
" 25..	8.00 P.M.	34°43′ N.	12°28′ W	773.5	21.6	20.4	20.5	N.E. Moderate.	2.88	....	Midway between Madeira and Lisbon.

Mean of CO_2 in Sea Air for Day = 3.011
" " " " " Night = 2.993

0.018

The general mean of the seventy-seven experiments being 3 parts CO_2 in 10,000 parts air, a proportion less by 1.63 parts in 10,000, than was found by Levy.

The differences in the results obtained by these two observers, can only be reconciled by a comparison of the methods employed. The method of von Pettenkofer, which was employed by Thorpe, possesses a much greater claim to accuracy than the eudiometric method of Regnault and Reiset, employed by Levy.

TABLE X.

Proportion of CO_2 in the Air of Tropical Brazil During Rainy Season. (*Thorpe*).

Date.	Hour.	Bar. m.m.	Temp. of Air. Dry.	Temp. of Air. Wet.	Wind, Etc.	CO_2 in 10,000 Vols. of Air. 1st Exp.	CO_2 in 10,000 Vols. of Air. 2d. Exp.	
1866. April 3.	4 20 P. M.	762.0	23.4	23.1	Light air. Overcast	3.19	3 14	After 6 hours heavy and incessant rain.
" 4.	3.00 P. M.	761.4	29.0	27.5	Little wind. Gloomy.	3.44	3.35	Just previous to a storm.
" 16.	11.20 A. M.	766.0	30.1	26.2	N.E. Light breeze.	3.47	.. ..	Cloudy. Much rain on previous night.
" 16.	3.45 P. M.	763.5	25 6	24.7	N.E. Gentle breeze.	3.22	3.13	After 1½ hours heavy rain.
" 18.	9.25 A. M.	766.0	27.2	25.0	N.E. Little wind.	3.27	3.12	Cloudy. Dull.
" 18.	3.05 P. M.	763.5	25 9	25.3	.. ..	3.22	.. .	After rain.
" 19.	2.30 P. M.	762.5	28.9	25.6	N.E.xE. Fine breeze.	3.30	3.12	Sunny.
" 21.	12.50 P. M.	764.0	33 3	26.6	N.E. Gentle breeze.	3 41	3.28	Fine.
" 23.	1.20 P. M	764.5	28.3	25.9	N.E. Gentle breeze.	3.12	3.27	Fine and sunny.
" 24.	2 35 P. M	764.0	32.3	25.6	N.E. Gentle breeze.	3.16	3.48	Clear.
May 4.	2.50 P M.	763.3	29.6	26.6	N. N.E. Fine breeze.	3.32	......	Fine.
" 7.	3.30 P. M.	762.0	26.9	24.6	Variable and light.	3.07	3 14	Gloomy.
" 12.	1.40 P. M	761.5	27.4	25.6	N. N.E. Fine breeze.	3.24	3.35	Gloomy. Just before wind and rain storm.
" 18.	12.15 P. M.	763.5	30.8	25 6	N.E. Gentle breeze.	3.32	3.28	....
" 21	12 45 P. M	762.5	29.8	25.6	N.E.	3.31	3.29	Fine and sunny.
" 23.	11.45 A. M.	764.5	32 2	27.2	Fine breeze.	3 45	3.32	Cloudy.
" 26.	1.00 P. M.	764.5	31.7	25.0	Fresh breeze.	3.49	3.30	Little rain for past 3 days. Fine.

The details of Thorpe's experiments on the Atlantic will be found in Table IX.

From his experiments Thorpe concludes:

(1.) That the sea does not act in increasing the amount of atmospheric carbonic acid.

(2.) But that, on the contrary, the air over the sea contains a much smaller proportion of carbonic acid than the air of the land,

although the influence of the sea in abstracting the gas from the atmosphere is not so great as the older experiments of Vogel[1] and Krüger[2] would indicate.

(3.) That the mean quantity of carbonic acid contained in the normal atmosphere over the ocean is 3.00 vols. in 10,000 vols. of air.

(4.) That the proportion is constant, or nearly so, in different latitudes.

(5.) That the proportion is not sensibly influenced by the different seasons of the year.

(6.) That the proportion does not experience any perceptible diurnal variations.

Müntz & Aubin[3] give the following:

TABLE XI.

Carbonic Acid Analyses Made on Board the Ship "Romanche" in 1883; *Open Air, Over the Sea.*

Sept. 20, South Atlantic,	Long., 42° 17′ west; Lat., 42° 37′ south.	2.74 CO_2 in 10,000
Sept. 28, " "	Long., 26° 17′ west; Lat., 25° 45′ south.	2.77 CO_2 " "
Oct. 1, " "	Long., 20° 32′ west; Lat., 23° 36′ south.	2.72 CO_2 " "
Oct. 4, " "	Long., 19° 55′ west; Lat., 16° 44′ south.	2.70 CO_2 " "
Oct. 16, North Atlantic,	Long., 22° 38′ west; Lat., 7° 10′ north.	2.49 CO_2 " "
Oct. 31, " "	Long., 27° 50′ west; Lat., 14° 40′ north.	2.70 CO_2 " "
	Mean,	2.68 CO_2 " "

This mean for the observations upon the high seas is almost identical with the mean of their observations in the Northern and Southern Hemispheres:

Northern Hemisphere = 2.84 CO_2 in 10,000 vols. air.
Southern Hemisphere = 2.56 CO_2 " " " "

Mean = 2.70 CO_2 " " " "
High seas, mean = 2.68 CO_2 " " " "

Thorpe's[4] experiments upon the air of tropical Brazil gave him as a result of 31 analyses a mean of 3.28 CO_2 in 10,000.

[1] Vogel—Ann. Phil. N. S., VI., 75.
[2] Krüger—Schw. T. XXXV., 379.
[3] Comptes Rendus, Tome, 98, 1884, p. 487.
[4] Thorpe—Jour. Chem. Soc., London, 1867, Vol. XX., p. 199.

His experiments were made at Para during the months of April and May, 1866.

Para, the principal port of entrance to the Amazon, is located on the river Gram-Para, about 80 miles from the sea, lat., 1° 27′ S.; long., 48° 28′ W., and is directly on the border of a vast forest, reaching to the sea. For the greater portion of the year the trade winds of the Atlantic blow across the forest.

The detailed results of his experiments made at this place will be found in Table X.

The direction of the wind at certain places is seen to have a slight effect upon the amount of CO_2 present in the atmosphere. Fr. Schulze[1] has demonstrated that in Rostock the air is seen to contain less of this gas when the wind is from the sea than when it comes from over the land. Blochmann[2] found the same to be true for Königsberg and Uffelmann[3] has confirmed Schulze's observations at Rostock.

The means of all of Uffelmann's observations at Rostock are as follows:

N.W.	wind	= 3.49	vols. CO_2	in 10,000	vols. air.
N.	"	= 3.38	"	"	"
E.	"	= 3.71	"	"	"
S.E.	"	= 3.62	"	"	"
S.W.	"	= 3.50	"	"	"
W.	"	= 3.58	"	"	"

The experiments are too few in number to permit of any positive conclusions being drawn.

After heavy rains, and particularly when they have continued for any considerable length of time, Uffelmann observed a diminution in the average proportion of CO_2 present in the air of the same place.

He found in the yard of the University at Rostock the following conditions:

April 26, 1887	Cloudy	= 3.66	CO_2	in 10,000	
" 27, "	After very heavy rain	= 3.40	"	"	
May 29, "	Heavens almost clear	= 3.58	"	"	
" 30, "	After heavy rain	= 3.39	"	"	
July 15, "	After very heavy rain	= 3.28	"	"	

It seems from these figures that a portion of the carbonic acid is washed from the atmosphere by the rain in its passage to the earth.

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[1] Schulze, Landwerthschaftl, Versuchstation, Bd. LXXIV.

[2] Liebig's Annalen, Bd. CCXXXVII.

[3] Arch. f. Hyg., 1888, p. 286.

This view is strengthened by the experiments of Reichardt[1], who found 2 c.c. of CO_2 in a litre of rain water.

On the other hand the proportion of carbonic acid in the air is seen to be very much greater during heavy snow falls and fog. Schulze[2] and Uffelmann[3] observed this, the latter finding for the same locality :

During snow storm,	December 18,	1886,	3.96 CO_2	in 10,000.
" " "	March 12,	1887,	3.67	" "
" " "	" 22,	"	3.81	" "
During Fog,	February 20,	"	3.74	" "
" "	" 22,	"	3.70	" "
" "	May 28,	"	3.96	" "
" "	" 29,	"	4.00	" "

Average for one year, daily observations at this place gave, under all conditions, 3.51 CO_2 in 10,000.

The results of analyses of the air at different altitudes, have led to opposing opinions. De Saussure,[4] in 1831, found that the air at mountain tops was richer in carbonic acid than that over the low lands. He attributes these differences to the action of the more abundant vegetation of the low lands in decomposing the carbonic acid in the atmosphere immediately above them—whereas, on the mountain tops, the vegetable growth is scant, and indeed frequently absent, so that there is an absence of this continuous draught upon the CO_2 and in consequence, its amount is not diminished by this cause. He believes, moreover, that the relative amount of moisture in the high and low-lying lands likewise plays a part in the diminution of the proportion of this atmospheric constituent—the moist low lands having the power to take up a greater proportion of the gas than the dry lands of the mountain tops.

The experiments of Tissandier,[5] led him to adopt a similar view. His results were obtained from samples of air collected during a balloon ascent. Tissandier found that the air at an altitude of 2,920 feet gave him 2.140 vols. of CO^2 per 10,000, and that at an altitude of 3,281 feet, he obtained 3.00 vols. CO_2 in 10,000. The results of the latter observer, are, as pointed out by Fodor,[6] open to question, by reason of the methods employed by him. He allowed the air which was to be analyzed

[1] Reichardt, Arch. f. Pharmacie, Bd. CCVI., p. 193.

[2] Ebenda.

[3] Ebenda.

[4] De Saussure, Ann. d. Chim. e. d. Phys. XLIV., 1831.

[5] Tissandier, Comptes Rendus, 1875, Tome 17, page 976.

[6] Fodor, "Luft, Boden und Wasser," Braunschweig, 1881.

to pass over potassium hydroxide, by which the carbonic acid contained in it was absorbed. The CO_2 was then liberated from its carbonate thus formed by the substituting action of other acids, and its volume measured eudiometrically, a method known to admit of a greater degree of errors than the process of titration now in vogue.

In opposition to these views stand the results of work done by Truchot,[1] Müntz & Aubin,[2] Angus Smith,[3] and Fodor.[4]

Truchot's analyses, made at different altitudes, resulted as follows:

				CO_2 in 10,000.
Clermont-Ferrand,	1,296	feet above sea-level,	mean of 3 analyses,	3.13.
Puy de Dome,	4,774	" "	Aug. 27th, -	2.03.
Pic de Sancy,	6,181	" "	Aug. 29th, -	1.72.

Müntz & Aubin's analyses at high altitudes, gave for Pic du Midi, 9,439 feet above sea, 2.86 CO_2 in 10,000.

Angus Smith's work, led him to lay down the following probable means for different altitudes:

High altitudes,	less than 1,000 feet	= 3.37 CO_2 in 10,000.
" "	between 1,000 and 2,000 feet	= 3.34 " "
" "	" 2,000 " 3,000 "	= 3.32 " "
" "	above 3,000 feet	= 3.36 " "

Smith's work, can hardly be accepted as showing any marked differences between the air at the altitudes in which his analyses were made. The means of his analyses, made at mountain tops in Scotland and over the low lands at the foot of these mountains, were:

Mountains, 3,281 feet high—average = 3.32 CO_2 in 10,000.
At foot of these mountains— " = 3 41 " "

If one considers for an instant, the ceaseless motion constantly in progress in the atmosphere at large, motion in the form of air currents, resulting from variations in temperature and from the natural diffusion between gases of different constitution, it appears somewhat irrational to formulate a law that an atmospheric stratum of one altitude would contain a constantly larger proportion of a gas than that at a higher or a lower level. It is reasonable to suppose, that at any given point of constant altitude, there may be variations from time to time in the proportion of its atmospheric constituents, but that it will

[1] Truchot, "Comptes Rendus," Tome 77, 1875.
[2] Müntz & Aubin, Comptes Rendus, Tome 92, pp. 247, 1299.
[3] Smith, "Air and Rain," 1872.
[4] Fodor, loc. cit.

always contain a larger or a smaller proportion of any of its constituents (conspicuously local causes being excluded) than another place a few hundred feet higher or lower, and equally favorably located, is opposed to all physical laws bearing on gases when allowed to circulate freely.

For the atmosphere immediately above the earth's surface, however, it is certain that at different levels, different proportions of carbonic acid exist; those layers next to the ground, containing constantly more of this gas than the layers a few feet above.

Believing the ground to be the main source from which the atmosphere receives its CO_2, and believing it to be the great cause of the fluctuations in the proportion of this gas, which are known to occur in the air of different places, Fodor was strengthened in this opinion by the result of comparative analyses which he made. His experiments were for the years 1877–78–79, at Budapest.

In each experiment a sample of air was taken from ½ to 1 c. m. above the ground, and, simultaneously, a second sample was analyzed from 2½ m. over the ground. His results were as follows:

TABLE XII.

	1877.		1878.		1879.	
	1 c. m. Above Ground.	2½ m. Above Ground.	1 c. m. Above Ground.	2½ m. Above Ground.	1 c. m. Above Ground.	2½ m. Above Ground.
January	4.78	....	3.03	3.72	3.32	3.71
February	4.25	....	3.37	3.64	2.79	3.66
March	2.29	4.50	3.69	3.56	2.48	....
April	1.55	3.98	3.85	3.34	....	....
May	4.62	4.13	5.22	3.88	3.94	3.47
June	5.84	4.68	3.77	3.40	4.18	3.53
July	4.12	4.11	4.23	3.52	3.93	3.57
August	4.74	4.12	6.69	3.87	4.56	3.68
September	6.75	4.24	5.45	4.05	4.32	3.90
October	5.66	4.16	4.43	4.15	3.80	3.76
November	5.02	4.14	3.91	3.82	....	....
December	3.15	3.79	....	3.84	....	....

The table shows, that for the greater portion of the year, the proportion of CO_2 in the air immediately above the ground, is greater than that found 2½ meters higher up.

It teaches also, that during many months in the year, the fluctuations in the amount of this gas present in the air immediately above the ground, are very much greater than that in the higher layers of the atmosphere.

It shows particularly, that each fluctuation, either an increase or diminution, in the proportion of CO_2 in the upper layers of the air, is preceded by a similar fluctutation in the air immediately over the ground.

From this it follows, that the proportion of carbonic acid in each of these lower layers of the atmosphere, stands in close relation, the one to the other—the lower layer acting as a regulator for those above it.

From the foregoing table, the conclusion may also be drawn, that the ground may possess the power of diminishing the CO_2 in the higher layers of the air, for in several instances it is seen, that the layer of air in close contact with the ground is poorer in CO_2 than that a few feet higher up. This is the case on rainy days, and especially is it so in spring time.

Fodor shows this diminution in the amount of CO_2, which is seen to occur in the lower layers of the air on rainy days, to be not entirely due to the absorption of this gas by the water, but rather to an actual chemical combination which occurs between it and the moistened ground. He demonstrated, experimentally, that if ground be moistened by water containing no carbonic acid, that it will actually take up from fifteen to twenty times as much carbonic acid as the same amount of water alone.

TABLE XIII.

Comparison Between the Amounts of Carbonic Acid Present in the Air of Florence at the Surface of the Ground and 18 *Meters Above the Surface.* (*Roster.*)

Date.	CO_2 in 10,000 Parts of Air at		Difference.
	Ground Level.	18 m. Above Ground.	
May 17–18	3.37	3.20	0.17
" 19–20	3.32	3.05	0.27
" 20–21	3.47	3.30	0.17
" 21–22	3.51	3.11	0.40
" 22–23	3.31	3.07	0.24
" 24–25	3.37	3.03	0.34
" 25–26	3.29	3.04	0.25
" 26–27	3.42	3.24	0.18
" 27–28	3.12	2.79	0.33
Mean	3.35	3.09	0.26

From the very exhaustive experiments made by Feldt, Heimann and Frey upon the air of Dorpat, we can gather but little to explain the fluctuations constantly in progress in the proportion of CO_2 in the air.

Each of these observers found monthly, daily and hourly, variations in the proportion of this gas, but were not able to demonstrate that these changes were a constant accompaniment of any condition.

For Spring, Summer and Fall, they found the proportion to be almost constant. For Winter, it was a trifle higher. In referring to this, Frey remarks that perhaps this difference may be due to the fewer experiments that were made in Winter, owing to inclemency of the weather, and partly to the additional consumption of oxidizable carbon compounds as fuel and for purposes of illumination.

TABLE XIV.

Means of Day and Night Observations Upon Atmospheric Carbonic Acid.

Place.	Day.	Night.	Observer.
Florence, at level of ground..	3.22	3.49	Roster.
8 meters above ground.... ..	3.46	3.76	Roster.
18 " " "	2 91	3.27	Roster.
Orange Bay, Cape Horn.....	2.563	2.556	Müntz & Aubin.
Dorpat...	2.58	2.69	Heimann.
"	2.66	2.67	Feldt.
Montsouris..	2.891	3.084	Reiset.
Andrassan, Scotland.........	3.40	3.88	Muir.

TABLE XV.

Daily Fluctuation of CO_2, as Observed by Frey at Dorpat.

Hour.	Feb., March, April, May, 1887.	June, July, Aug., Sept., 1888	Oct., Nov., Dec., Jan., 1889.	Mean for the 12 Months.	Number of Experiments.
9–12 A. M.	2.49=mean of 28 exp.	2.56=mean of 57 exp.	2.59=mean of 95 exp.	2.55	180
12– 3 P. M.	2.66 " 95 "	2.53 " 102 "	2.53 " 102 "	2.56	299
3– 6 "	2 73 " 83 "	2.45 " 90 "	2.67 " 101 "	2.62	274
6– 9 "	2.69 " 66 "	2.72 " 130 "	2.64 " 69 "	2.66	265
9–12 "	2.63 " 12 "	2.92 " 40 "	2.61 " 88 "	2.69	140
12– 3 A. M.	2.68 " 40 "	3.03 " 67 "	2.80 " 21 "	2.88	128
3– 6 "	....	2.86 " 26 "	2.81 " 19 "	2.84	45
6– 9 "	2.46 " 16 "	2.71 " 89 "	2.61 " 61 "	2.64	166

Heimann believed to have demonstrated that the proportion of carbonic acid in the air, was directly proportional to the barometric pressure, and inversely, to temperature and humidity.

Frey, who repeated the experiments with this point in view, was unable to confirm the observations of Heimann.

TABLE XVI.

Daily Fluctuation of Carbonic Acid in the Air, Expressed in Parts per 10,000.

Date.	Place.	CO_2 Min.	CO_2 Max.	Difference.	Analyst.
1869–71	Rostock	2.25	3.44	1.19	Schulze.
—	Lund	2.37	3.27	0.90	Claeson.
—	Tabor	3.02	4.07	1.05	Farsky.
1874	Dahne	2.70	4.17	1.47	Fittbogen.
1830	Geneva	3.15	7.37	4.22	Saussure.
—	Madrid	2.00	5.74	3.74	Luna.
—	Manchester	2.85	9.00	6.15	Smith.
1877–79	Budapest	2.33	4.17	1.84	Fodor.
1877–85	Montsouris. Paris	2.53	3.60	1.07	Levy.
1875	Paris	2.91	3.52	0.61	Reiset.
—	Paris	2.88	4.22	1.34	Müntz & Aubin.
1882	Pic du Midi	2.69	3.01	0.32	Müntz & Aubin.
1886	Florence	2.71	4.19	1.48	Roster.

TABLE XVII.

Difference Between the Amount of Carbonic Acid Present in the Air During the Day and Night. (*Roster.*)

Height Above the Ground at Which Sample Was Taken.	CO_2 in 10,000 Vols. of Air. Day.	CO_2 in 10,000 Vols. of Air. Night.	Difference.
At level of ground	3.22	3.49	0.27
8 m. above ground	3.46	3.76	0.30
18 m. " "	2.91	3.27	0.36

TABLE XVIII.

Monthly Variations in the Proportion of Free Carbonic Acid in the Air of Different Places. Expressed as Vols. of CO_2 in 10,000 *Vols. of Air.*

Months.	Montsouris, 1871-85.	Budapest, 1877-79.	Florence, 1886.	Rostock, 1886-87.	Dorpat, 1888-89.	Orange Bay, Cape Horn, 1882-83.
January	3.04	3.72	2.92	3.65	2.69	2.55
February	2.97	3.65	2.98	3.68	2.81	2.71
March	2.96	4.08	2.99	3.61	2.79	2.55
April	2.98	3.66	2.95	3.50	2.50	2.54
May	2.99	3.84	3.07	3.51	2.57	2.65
June	3.03	3.87	3.59	3.42	2.50	2.50
July	2.99	3.73	3.28	3.30	2.61	2.75
August	2.95	3.89	3.30	3.28	2.83	....
September	2.97	4.06	3.20	3.34	2.67	....
October	2.90	4.02	3.00	3.54	2.56	2.50
November	2.87	4.03	3.04	3.63	2.72	2.60
December	2.94	4.03	2.99	3.67	2.50	2.53

TABLE XIX.

Table Showing Seasonal Variations in the Proportion of Free Atmospheric Carbonic Acid. Expressed as Vols. of CO_2 in 10,000 Vols. Air.

Place.	Winter.	Spring.	Summer.	Autumn.
Dahne[1]	3.24	3.37	3.34	3.39
Budapest[2]	3.83	3.84	3.83	4.04
Montsouris[3]	3.09	3.07	3.05	3.11
Florence[4]	2.98	3.01	3.43	3.39
Dorpat[5]	2.72	2.61	2.66	2.61
Rostock[6]	3.67	3.54	3.34	3.50
Mean	3.26	3.26	3.28	3.34

Ammonia.—The most conspicuous of the nitrogenous products of decomposition that are found in the air is ammonia. It is everywhere present, though in amounts that are subject to the widest fluctuations. The range of this variation can, perhaps, be best understood by reference to the accompanying tabulated observations made at different places (taken from Roster's book, "L'Aria Atmosferica.")

TABLE XX.

Atmospheric Ammonia.

Date.	Place.	Mgs. of NH_3 in 1 C. M. of Air.	Analyst.
May	Mühlhausen, 4 rainy days	0.4250	Graeger.
June, July	Irish coast	4.6400	Kemp.
Aug. and Sept., 1848	Wiessbaden, mean for 40 days.	0.1720	Fresenius.
December	Boston	1.5500	Horsford.
May and April	Caën (mean)	0.6450	Pierre.
	Lyons, mean of different altitudes, 7.5 m.–23 m.	0.4450	Bineau.
Winter and Summer	Calurie	0.0910	"
July, Aug. and Oct.	Clermont, Fearand, mean of 7 observations	1.5760	Truchot.
	Puy de Dome (1,446 m.)	2.1500	"
	Pic de Sancy (1,884 m.)	5.3520	"
	Paris	0.0320	Ville.
1877–79	Budapest	0.0413	Fodor.
1877–79	Montsouris	0.0245	Levy.
1879	Glasgow	0.0310	Official.
1875–76	Paris, mean for the year	0.0225	Schloesing.

[1] Fittbogen & Haesselbarth, *loc. cit.*
[2] Fodor, *loc. cit.*
[3] Annuaire d. l'obs d. Montsouris, 1876, '77, '78, '79.
[4] Roster, *loc. cit.*
[5] Frey Dissertation, *loc. cit.*
[6] Uffelman, *loc. cit.*

A fair average, however, of the amount of ammonia normally present in the atmosphere may be obtained from the following table:

TABLE XXI.

Paris (analyses in the city)	0.0320	mgs. in 1 cubic meter of air
Budapest (Fodor's analyses)	0.0413	" " " " "
Montsouris (Levy's analyses)	0.0245	" " " " "
Glasgow (official analyses)	0.0310	" " " " "
Paris (Schloesing's analyses)	0.0225	" " " " "
Mean	0.0304	" " " " "

Ammonia, though present in the atmosphere in very small amounts, can nevertheless be demonstrated at all points upon the earth's surface.

Its relative proportion, is seen to undergo such wide fluctuations at different localities, as to make it probable that it is largely influenced by local conditions.

It exists in the atmosphere mainly as a result of decomposition of nitrogenous substances, though a certain proportion of it arises as a result of various industries. It is present in small amounts in illuminating gas, and can be demonstrated in traces in the exposed air. It is usually combined with carbonic acid in the air, and in small amounts with nitrous acid.

With elevation of temperature, and in the presence of sufficient moisture, the amount of this compound present in the atmosphere in the neighborhood of decomposing matters, is seen to increase. From these points, it is in part disseminated through the atmosphere, to be again, in part, returned to the earth with the rain.

Fodor found the seasonal variations in the amount of atmospheric ammonia of the air of Budapest, as depending mainly upon variations in temperature, to be as follows:

Winter,	0.0251	mgs. NH_3 in 1 cu. meter of air at Budapest.
Spring,	0.0303	" " " " "
Summer,	0.0488	" " " " "
Autumn,	0.0334	" " " " "

Experiments have led us to believe, that ammonia does not exist in the air as a result of diffusion from the deeper layers of the soil, as was at one time supposed, but rather as a result of the manifold processes of decomposition going on upon the surface of the ground.

The experiments of Fodor demonstrated that the amount of ammonia present in the atmosphere is dependent entirely upon local causes: it is most affected by moisture and temperature. It is seen to diminish with almost mathematical regularity, with the existence of rainy weather and fall of temperature, and to again increase as the

temperature rises after a rainy spell. Its amount was changed but little, or not at all, by winds from the different points of the compass, and particularly was this the case with winds from the sea, which. according to the doctrine of Schlöesing, should have caused an increase. It cannot come from the "ground air," properly so called, as the following experiments of Fodor show:

The amount of ammonia present in 1 cubic meter of air from the soil. (Fodor).

		1 meter deep.	4 meters deep.
March to May,	ground air	0.0198 mgs.	0.0471 mgs.
June " September,	"	0.0277 mgs.	0.0444 mgs.
October " December,	"	0.0089 mgs.	0.0167 mgs.

The official observations made at Glasgow, point also to local conditions as potent factors in influencing the amount of ammonia in the air.

In 1 cubic meter of air from different localities, the following results were obtained:

For the air at the Western Infirmary	0.015 mgs.
" " Hospital, Kennedy Street	0.019 mgs.
" " Sailors' Home	0.024 mgs.
" at Colton	0.044 mgs.
" at Sterling Square	0 053 mgs.

The more densely populated a locality, and the greater the extent of manufacture in progress, the higher is the proportion of atmospheric ammonia.

Another factor that is potent in causing irregularities in the relative amount of ammonia in the atmosphere, is rain. With every rainstorm, a certain amount of this substance is washed from the air, as can be demonstrated not only by a diminution in the amount present in the free atmosphere, at the point at which the rain fell, but also by its presence in the collected rain water.

Schlöesing's experiments, made at Paris, give as a mean amount of ammonia in the air on rainy and dry days for one year, the following figures:

Rainy days, 0.0175 mgs. NH_3 in 1 cubic meter of air.
Dry " 0.0193 " " " "

From Fodor's standpoint, the hygienic significence of free ammonia in the atmosphere are its indications of the existence of nitrogenous decomposition in progress at neighboring points; it may be taken as an index of the intensity of this decomposition, and may serve as indicator of the presence of other volatile organic products thrown off along with it from the putrefying substances.

CHAPTER V.

CONDITIONS WHICH MAKE VENTILATION DESIRABLE OR NECESSARY—PHYSIOLOGY OF RESPIRATION—GASEOUS AND PARTICULATE IMPURITIES OF AIR—SEWER AIR—SOIL AIR—DANGEROUS GASES AND DUSTS IN PARTICULAR—OCCUPATIONS, OR PROCESSES OF MANUFACTURE—DRYING ROOMS.

BEARING in mind the composition and the more important physical properties of the normal or free atmosphere, we come now to the consideration of the changes produced in it by animal life, and by the conditions of human habitations and occupations, which make it desirable or necessary to dilute and remove the air which has thus been rendered more or less unfit for respiration, and to supply fresh and pure air in its stead in rooms and enclosed spaces.

In the open air, under ordinary circumstances, as has been shown in a previous chapter, the difference between gases of different densities and the action of atmospheric currents produce such a rapid and thorough mixture and dilution of gaseous impurities escaping into it, that they are soon made innocuous and inoffensive. Yet this is not always the case, and in enclosed spaces or rooms occupied by men, some accumulation of such impurities almost always occurs, requiring the adoption of special means to prevent it from becoming excessive.

The first group of such impurities to be considered is that due to respiration, and to exhalations from the skin and alimentary canal.

Pure air contains no stored force, and cannot properly be called a food. Nevertheless, its oxygen is as essential to nourishment, growth, and manifestations of muscular force as are the substances usually reckoned as alimentary principles. The essential feature of animal respiration is the taking in of oxygen and the excretion of carbonic acid, and this is effected chiefly by the physical process of diffusion between the air and the gases of the blood through the thin membranes forming the walls of the air cells and capillaries of the lungs. In the human lungs there are between five and six millions of such air cells or vesicles, and their superficial area is about 975 square feet. They are

connected by the bronchial tubes with the wind-pipe, which communicates with the external air through the nose and mouth.

The lungs are contained in the chest cavity, which they exactly fill so long as no opening is made in the chest wall, accommodating themselves to variations in its size and shape. When the chest cavity is made larger by descent of the diaphragm or by ascent of the ribs, the action is similar to that of expanding of a bellows, and the air rushes in through the nose, mouth and air passages, distending the expansible lung and equalizing the atmospheric pressure on the interior and exterior walls of the chest. This act of inspiration is a muscular movement. The lungs contain a large amount of elastic tissue which is in a state of constant tension, and when the muscular effort required to expand the chest relaxes, the lungs contract, expelling a portion of the air which they contain. Ordinary expiration is thus for the most part due, not to muscular compression, but to the contractility of the lung tissue.

The lungs never give out all the air they contain ; after the most complete expiration possible there will still remain in them from 100 to 130 cubic inches of air, which is called residual air.

After a normal quiet respiration, an additional quantity of air can still be expired from the chest equal to about 100 cubic inches, which is called reserve or supplemental air. The volume of air which is taken at each inspiration and expiration is called tidal air, and is equal to about 30 cubic inches, so that from one-seventh to one-tenth of the air in the lungs is renewed at each respiration. In the adult the number of respirations varies from 16 to 24 in the minute—the frequency being affected by the position of the body, the age, the state of activity of the person, the density of the surrounding medium, and the temperature of the blood. Evidently a large part of the mechanism for the interchange of gases in the lungs must be by the process of diffusion from the larger air passages.

The changes produced in air by respiration are: elevation in temperature, increase of moisture, increase in volume, and changes in its chemical composition.

At the average temperature of 70° F., the temperature of the air as it leaves the lungs should be about 97° F., which implies an equivalent loss of heat from the body. When the external temperature is very low, that of the expired air sinks a little; thus at 42° F. it becomes 88° F. If the external temperature is above 100° F., the expired air may be cooler than that which is inhaled—the temperature depending on the relative temperature of the blood and the surrounding atmosphere.

The average loss of heat from the body in 24 hours due to respiration alone, is calculated at 3.5 calories, which must necessarily again appear as such in the surrounding air, and consequently elevate its temperature.

Although inspired air almost always contains more or less vapor of water, it is rarely saturated when it enters the body; however, it carries off as much aqueous vapor as it is possible for it to hold at the temperature at which it is expired—thus it may be considered to be saturated at the temperature of 97° F. The amount of water removed from the body by respiration of course varies with the temperature and condition of humidity of the inspired air, but as an average for 24 hours the amount may be taken as 255 grams (9 ounces). For the evapora-

CORRECTIONS:

Page 87, line	2,	*instead of*	"3.5 calories,"	*read*	"85,000 small calories."
" " "	14,	" "	"7.2 calories,"	"	"192,000 small calories."
" " "	15,	" "	"10.7 calories,"	"	"275,000 small calories."

crease depending on the amount of respiration going on, and the amount of change occurring in the air of the room.

The chemical alterations in air due to respiration are diminution of the amount of oxygen, and increase in the proportion of carbonic acid, together with the addition of certain volatile organic compounds, of whose nature we as yet know but little. Expired air contains about 5 per cent. less oxygen, and a little more than 4 per cent. more of carbonic acid than that which is inhaled.

Comparing the chemical composition of 100 parts of the free atmosphere with 100 parts of expired air, their compositions would be as follows:

Free atmosphere	Oxygen	20.8
	Nitrogen	79.2
	Carbonic Acid	0.0 3-4 Vol.
Expired air	Oxygen	15.4
	Nitrogen	79.2
	Carbonic acid	4.3 3-4 Vol.

connected by the bronchial tubes with the wind-pipe, which communicates with the external air through the nose and mouth.

The lungs are contained in the chest cavity, which they exactly fill so long as no opening is made in the chest wall, accommodating themselves to variations in its size and shape. When the chest cavity is made larger by descent of the diaphragm or by ascent of the ribs, the action is similar to that of expanding of a bellows, and the air rushes in through the nose, mouth and air passages, distending the expansible lung and equalizing the atmospheric pressure on the interior and exterior walls of the chest. This act of inspiration is a muscular movement. The lungs contain a large amount of elastic tissue which is in a state of constant tension, and when the muscular

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Since air leaving the lungs saturated with moisture at 97° F. must lose a portion of this moisture from condensation, as its temperature, falls to that of the average temperature of inhabited rooms—namely, 65 to 70° F., we see that the air of a room containing living men and other animals will be increased in temperature—the amount of the increase depending on the amount of respiration going on, and the amount of change occurring in the air of the room.

The chemical alterations in air due to respiration are diminution of the amount of oxygen, and increase in the proportion of carbonic acid, together with the addition of certain volatile organic compounds, of whose nature we as yet know but little. Expired air contains about 5 per cent. less oxygen, and a little more than 4 per cent. more of carbonic acid than that which is inhaled.

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Free atmosphere	Oxygen	20.8
	Nitrogen	79.2
	Carbonic Acid	0.0 3-4 Vol.
Expired air	Oxygen	15.4
	Nitrogen	79.2
	Carbonic acid	4.3 3-4 Vol.

Taking the daily respiration by volume as 10,800 litres (346 cubic feet) of air with a loss of 5 per cent. of oxygen and a gain of 4.37 per cent. of carbonic acid, it is seen that the amount of oxygen taken up through the lungs in 24 hours is 583.2 litres (20.4 cubic feet) by volume or 833.9 grams (12.818 grains) by weight.

The amount of carbonic acid excreted from the lungs in the same time is 464.4 litres (16.25 cubic feet) by volume, or 910 grams (14.105 grains).

As we proceed in these studies, it will be seen that one of the most universally employed indices for the determination of the extent to which pollution of air, due to human exhalation and transpiration, is going on, in enclosed spaces, is the excess of carbonic acid over and above the amount usually found in the air. Not that the gas has any hygienic significance within the limits ordinarily observed, but experience has shown a constant parallel between the rate of its production and the amount of organic impurities thrown off by animals and human beings.

The ratio between the amount of oxygen absorbed and the amount of carbonic acid exhaled varies in different animals. This ratio, called by Pflüger the respiratory quotient, being $\frac{CO^2}{O}$ is from 0.9 to 1. in herbivora, while in carnivora it is from 0.75 to 0.8. In man it is 0.87.

The following table shows for different animals the amount of oxygen used per kilogramme of body weight per hour. * * * (I. Munk, Physiologie des Menschen, etc., 1888. p. 82).

Animal.	o in Grams.	Respiratory Quotient. $\frac{CO^2}{O}$
Cat	1.007	0.77
Dog	1.183	0.75
Rabbit	0.918	0.92
Hen	1.300	0.93
Small singing birds	11.360	0.78
Frog	0.084	0.63
Cockchafer	1.019	0.81
Man	0.417	0.78
Horse	0.563	0.97
Ox	0.552	0.98
Sheep	0.490	0.98

Smaller animals, therefore, have, as a rule, greater intensity of respiration than larger ones. In small singing birds the intensity is very remarkable, and it will be seen that they require ten times as

much oxygen as a hen. On the other hand, the intensity is low in cold-blooded animals, Thus a frog requires 135 times less oxygen than a small singing bird. The need of oxygen is therefore very different in different animals. A guinea-pig soon dies with convulsions in a space containing a small amount of oxygen, while a frog will remain alive many hours in a space quite free of oxygen. It is well known that fishes and aquatic animals generally only require a small amount of oxygen, and this is in accordance with the fact that sea-water contains only small quantities of this gas.

Aquatic breathers, however, if they live in a medium containing little oxygen, have the advantage that they are not troubled with free carbonic acid. One of the most striking facts discovered by the Challenger chemists is that sea-water contains no free carbonic acid, except in some situations where the gas is given off by volcanic action from the crust of the earth forming the sea-bed. In ordinary sea-water there is no free carbonic acid, because any carbonic acid formed is at once absorbed by the excess of alkaline bases present. Thus the fish breathes on the principle of Fleuss's diving apparatus, in which the carbonic acid formed is absorbed by an alkaline solution. (See *British Medical Journal*, No. 1442, August 18, 1888.)

The organic matters contained in expired air are small in quantity and of unknown nature. If a large quantity of such air be drawn through distilled water, or if its moisture be condensed by cold, the liquid thus produced contains nitrogenous matter, has a peculiar unpleasant odor, and usually soon putrifies. The free air also contains combined nitrogen in the form of salts of ammonia of nitrous or nitric acid and of organic matters, and the quantity of these may be approximately determined by the methods for determining ammonia and albuminoid ammonia.

An account of the various methods used for this purpose may be found in a report on the subject of organic matter in the air made by Professor Ira Remsen, and published in the National Board of Health Bulletin, Vol. 2, 1880, p. 517.

Professor Remsen drew from 50 to 100 litres of the air to be tested through a tube filled with coarsely-powdered pumice stone moistened with distilled water. When the measured amount of air had been drawn through this, the pumice stone was brought into a perfectly clean flask and 500 cc. of distilled water added, and this water was then tested for ammonia and albuminoid ammonia by the usual methods. The quantity of albuminoid ammonia thus found to be derived from organic matters is stated to be per 1,000 cubic

meters: in external air from 0.051 to 0.345 grams; in laboratory air from 0.28 to 0.44 grams; in air contaminated by respiration, 0.309 to 0.339 grams. His conclusion is that air contaminated by respiration contains more than the usual amount of albuminoid ammonia. In a paper on the estimation of nitrogenous organic matter in air (*Lancet*, 1872, Vol. 2, p. 628-9), W. A. Moss reports the number of milligrams of organic matter found in one cubic meter of air to be in the external air 0.035 to 0.192; in hospital wards 0.197 to 1.307; in a privy 0.86, and in respired air 0.1 to 0.54. In a paper on analyses of air published in the *American Chemical Journal*, Vol. 1, 1879, p. 263, Mr. Van Slooten gives the results of some determinations made in New Orleans during the epidemic of yellow fever in 1879 showing from 250 to 350 grains of albuminoid ammonia per million cubic feet of air during the epidemic month (September) and from 45 to 90 grains during November, but the reliability of his work is questioned by Professor Remsen. The results of analyses made in Glasgow and in Paris indicate that the proportion of ammonia and of albuminoid ammonia increases in the winter months.

Experiments have been made by Carnelley and Mackie to determine the amount of organic matter in undiluted expired breath. "For this purpose the observer inspired the air of the room through his nose, and expired through the mouth into a closed bottle of about 3½ litres capacity, and provided with a small outlet tube for the escape of the excess of expired air. This bottle was maintained at a temperature of about 45° C. by immersion in warm water, in order to prevent condensation of moisture from the breath. When the bottle was full of expired air, for which 50 expirations were considered sufficient, the temperature of the enclosed air was observed, the inlet and outlet tubes closed, and the bottle removed from the bath and allowed to cool down to the temperature of the room, when the inlet tube was opened and air allowed to enter to fill the partial vacuum. The temperature of the enclosed air was again observed, and the amount of organic matter determined in the usual way. A determination of the amount of organic matter in the air of the room was likewise made at the same time. The proportion of expired and unrespired air of the room in the bottle could be found by calculation. Then, by deducting from the total organic matter that present in the known proportion of unrespired air, the difference gave the amount of organic matter in undiluted breath. Care was taken to breathe as nearly as possible in a natural manner. The results obtained were as follows:

Observer—A.			Observer—B.		
Total in Expired Air.	In Air of Room.	Excess in Expired Air.	Total in Expired Air.	In Air of Room.	Excess in Expired Air.
3.3	1.6	1.7	6.5	3.0	3.5
12.4	3.2	9.2	12.2	1.6	10.6
5.8	1.6	4.2	13.3	4.7	8.6
11.8	2.2	9.6	13.1	1.9	11.2
15.6	2.0	13.6	10.1	2.3	7.8
Average per litre		7.6	Average per litre ..		8.3

The above determinations were mostly made on different days. According to these experiments the amount of oxidizable organic matter in breath is by no means constant, but varies from time to time, nor is the quantity so great as one might have expected. It is possible, however, that the organic matter in freshly expired breath is not in a condition to readily reduce permanganate, but after exposure for some time in the air it may undergo such a change as will render it more readily oxidizable."*

"The term 'organic matter,' as explained by the authors, is a very indefinite one, and really signifies the bleaching action of the air on a dilute solution of potassium permanganate acidified with sulphuric acid. It therefore includes not only organic matter properly so called, but those substances which air sometimes contains, such as sulphuretted hydrogen, sulphurous acid, etc., which also bleach permanganate solution. Even the organic matter itself may be of very different kinds, and vary considerably as regards its influence upon health, some doubtless being quite harmless, whilst some may exert a very deadly effect. In so far, therefore, as the method does not distinguish between these various constituents of air, but brings them all into the same category, it is a very imperfect method. But, as no better process has yet been devised, it is the only one which has been at our disposal."†

* Philosophical Transactions of the Royal Society of London. Vol. 178. (B) p. 87.

† Philosophical Transactions of the Royal Society of London. Vol. 178. (B) p. 62.

The following table* is a summary of the results obtained from examination of the air in the streets, schools and hospitals in Dundee and Perth during the winter and spring of 1885–86, by Carnelley, Haldane, and Anderson.

The carbonic acid is stated as the number of volumes contained in 10,000 of air.

The organic matter is stated by the volume of oxygen required to oxidize the oxidizable organic matter in 1,000,000 volumes of air.

The micro-organisms are represented by the number per litre of air which will grow on Koch's nutrient jelly kept in a room under ordinary conditions.

	Carbonic Acid.	Organic Matter.	Total Micro-organisms.	No. of Cases.
	Mean.	Mean.	Mean.	
With 2– 4 volumes of carbonic acid................	2.7	5.6	1.9	56
" 4– 6 " " "	4 9	6.1	3.5	27
" 6– 8 " " "	7.3	10.4	29.7	25
" 8–10 " " "	8.9	9.5	33.5	26
" 10–12 " " "	11.1	11.4	79.6	29
" 12–15 " " "	13.3	11.8	36.3	27
" 15–20 " " "	17.0	13.0	137.0	31
" 20–30 " " "	22.9	13.6	82.0	12
" 30 and above " "	37.1	19.8	53.0	9
With 0– 2.8 vols. oxygen required for organic matter	4.3	1.6	5 3	21
" 2.8– 5.6 " " " " "	6.8	4.2	10.1	52
" 5.6– 8.4 " " " " "	9.7	7.2	34.1	58
" 8.4–11.2 " " " " "	10.7	9.7	29.2	24
" 11.2–14.0 " " " " "	11.9	12.6	88.3	31
" 14.0–16.8 " " " " "	16.6	15.4	57.1	17
" 16.8–22.4 " " " " "	18.5	19.3	145.0	17
" 22.4 and above " " " "	18.8	29.7	87.0	15

In 1887–88, Brown Séquard and d'Arsonval, reported to the Society of Biology of Paris, that as the result of repeated experiments they found that air expired from the lungs contains a volatile poison belonging to the class of organic alkaloids and resembling in its effects a ptomaine. The condensed liquid from expired air, contains this poison, and a few cubic centimetres of it injected into a rabbit produced death.

*Philosophical Transactions of the Royal Society of London. Vol. 178. (B) 1888, p. 86.

Somewhat similar results had been obtained by previous observers, by enclosing animals in glass cases, absorbing the carbonic acid produced and supplying oxygen, death following in a short time.

On the other hand, Hermann, (Arch. f. Hyg. I, 1883), Dastre and Loye (Mémoires de la Soc. de biol. 1888–91), and others report results which are totally contradictory ot those mentioned above, denying that the condensed fluid has any toxic qualities.

Lehmann & Jessen (Arch. f. Hygiene, x, p. 367), state as a result of their work upon this subject:

(1) That the water obtained from expired air by condensation, when unmixed with saliva and other matters, is a clear, odorless fluid, of neutral reaction, in which traces of ammonia and hydrochloric acid can be detected. Upon being heated it gives off a peculiar odor. It contains a small portion of organic matter, but poisonous alkaloids could not be detected by any of the analytical methods at their disposal.

(2) The only crystallizable bodies detected by them, were crystals of lime which came from the walls of the glass apparatus employed.

(3) Neither the condensed vapor nor its distillate, when injected either subcutaneously or into the peritoneal cavity of rabbits, had any effect whatever, though large doses were employed.

(4) Experiments upon human beings in which the individual was caused to inspire air that had passed through the condensed vapor of expiration were entirely without toxic results.

The matter is one which requires much more investigation, but in the meantime it is certain that expired air contains substances which give it a peculiar odor, which produce discomfort and a feeling of oppression when present in quantity in air inhaled—and which, when concentrated, are probably dangerous, and the cause of some of the bad effects due to overcrowding and insufficient ventilation. There appears to be a definite relation between the odors caused by these substances and the amount of carbonic impurity due to respiration present, as will be more fully explained in the chapter on quantity of air desirable for ventilation. These substances when concentrated and injected into the blood of animals may, or may not, kill them—but this proves nothing as to their effects when inhaled by man.[1]

A certain amount of carbonic acid and large quantities of watery vapor are exhaled by the skin, and it is possible that a small amount of oxygen is absorbed through the skin, but the gaseous impurities added

[1] See for a critical review on this subject: "Sur la toxicité de l'air expiré," par Dr. Richard, Rev. d hyg., 1889, XI., p. 338.

to the air from the skin, are small in amount and importance. The particulate matters passing into the air from the skin in the form of epithelial scales are of more importance—but only when this epithelium comes from diseased bodies, and may thus be the means of conveying specific causes of disease.

By measurement, the expired air is found to be greater in volume than it was when inspired. This is due in part to its expansion under the influence of increased temperature, and, in part, to the additional amount of water vapor which it now carries. If, however, the expired air be dried and reduced to the same conditions of temperature as it had when inspired, we shall find that it has actually lost in volume; for as we saw 5.4 per cent. by volume of oxygen is taken up in the lungs, and only 4.3 per cent by volume of carbonic acid is given off to replace it, making a loss in volume in each 100 parts of air respired of 1.1 per cent. In other words, for every 100 parts by volume of air inspired (measured under normal conditions of temperature and pressure), only 99 parts are expired—and this explains the discrepancy in the two formulæ, in which the composition of free air and respired air are compared. Of the alterations found to take place in the air as a result of being breathed, perhaps those of greatest moment in the case of overcrowded, badly ventilated apartments are the rise in temperature and the excessive accumulation of watery vapors. As a result of these changes in the condition of the air, the heat-regulating processes of the body are more or less impeded, and in extreme cases death has been known to result.

Not unfrequently the co-existence of high temperature and excessive relative humidity occurs in the open atmosphere, and it is just at such times that the greatest number of sun-strokes are observed.

In perfectly dry air astonishingly high temperatures may be borne without any marked evil effects, for here the heat which is lost in the process of evaporation from the surfaces of the body prevents the internal rise of temperature, which is so deleterious to the proper functions of the tissues. Evaporation is here favored rather than retarded, and, as we know that with an increase in evaporation more heat is required, it is plain that so long as this hot air is dry, there is but little fear of any marked rise of temperature in the body.

If, however, this hot air is charged with a large amount of moisture we find a decided obstruction to evaporation, the obstruction being proportionate to the amount of water already present in the air.

Under such conditions the cooling effect of evaporation from the surfaces is greatly diminished and there is, in consequence, a rise of internal temperature. With the rise of body-temperature the chemical

changes which are going on in the tissues, become more and more exaggerated until they reach a point quite incompatible with life. Experiments upon lower animals have demonstrated that life ceases when the temperature of the tissues reaches 120° F. (49° C.), the approach of death being announced by beginning rigidity of the muscles.

The "black hole" of Calcutta is an extreme instance of this coexistence of high temperature and excess of moisture in the air of an enclosed apartment.

On the capture of Fort William in Calcutta,[1] in 1756, by the Nawab of Bengal, the Europeans who remained surrendered, and were driven at the point of the sword into the guard room, a chamber scarcely 20 feet square, with but two small windows, which were strongly barred with iron. Into this on a sultry night, 146 men were pressed, giving to each an area of less than 18 inches square. Very soon after they were crowded in, an almost incredibly profuse perspiration broke out upon them, which was followed by consuming and increasing thirst. They became furious and loaded the guards with insults to provoke them to fire, in which they failed. They made most furious cries for water; a little of it was brought to them in hats and forced through the bars. The stronger forced their way to the window and bore down and trampled to death the weaker ones. By half-past eleven most of the living were outrageous and the others quite ungovernable. At six in the morning the order arrived for their release. At that time only 23 were left alive, and so exhausted were the survivors that more than 20 minutes elapsed before they could remove the dead from the door so they could make sufficient opening to pass out one at a time. Most of those who survived were affected with a form of fever resembling typhoid, which was followed by an eruption of large and painful boils.

Somewhat similar results occurred on the steamer "Londonderry," when 150 passengers were confined in a small cabin for several hours, and 70 of them died.

Another source of gaseous pollution for the air of dwellings is the material employed in their illumination. As a result of the combustion of the ordinary illuminating agents, quite a group of volatile bodies are given off—their nature and amount depending largely upon the nature of the material employed and the completeness of combustion.

[1]Howell, John S., Relation of the deplorable death of English and other persons suffocated in the Black Hole at Fort William, Calcutta, etc. London, 1756, 8vo.

The most conspicuous changes wrought in the air in which gas or oil (for the products of both are about the same) are burned are elevation in temperature, the addition of water-vapor, carbon monoxide, carbon dioxide, nitric and nitrous acid, compounds of ammonia and of sulphur, marsh gas, carbon particles and acids of the fatty group. Aside from the gases given off as products of combustion in the process of illumination, it must be borne in mind that for producing combustion a certain amount of oxygen is needed, for which the burning material must draw upon the stock in the air of the apartment.

In the case of gas an ordinary small burner will burn about 3 cubic feet per hour, or in an evening of four hours from 10 to 12 cubic feet. Approximately the burning of each cubic foot of gas requires 1.12 cubic feet of oxygen, or 5.33 cubic feet of air, so that for the above interval of four hours about 64 cubic feet of air would be required for the combustion alone of the gas from a single burner, to say nothing of the amount that should be supplied in order to dilute the gaseous products from this burner to a point at which they could not be appreciated. It will be seen, then, where illumination by means of burning substances, as gas, oil, fats, etc., is employed on a large scale, its effect must be considered in calculating for the amount of ventilation necessary. In small apartments, however, it is generally conceded that if the amount of day ventilation is properly calculated, no increase to cover the requirements of illumination will be necessary.

The subject will be gone into more in detail in the chapter on "Calculation of amount of ventilation necessary under different circumstances."

Beside deleterious gases and accumulation of water-vapors, certain solid matters are found in the air of apartments.

As was demonstrated by Tyndall, the coarser of these solid matters floating in the air may be seen dancing in a ray of sunlight admitted to a darkened chamber. For the most part these objects are harmless bits of inorganic dust due to the wear and tear upon floors, furniture and hangings of the room. Upon some of these dust particles, however, are deposited microscopic living plants, which possess biological characteristics quite as distinctive as those seen in the different members of the animal kingdom. These very small plants belong to the family of Bacteria. They have a variety of physiological functions, some of them being concerned in specific fermentative changes, others giving rise to what we recognize as decomposition, a large number having the power of producing brilliant pigment pro-

ducts, and perhaps the smallest group being those directly concerned in the causation of disease.

To most people the word "bacteria," almost without exception, is connected with disease. Such an idea is erroneous. The vast majority of the members of the group of organisms are our benefactors, and only a very small proportion of them are directly concerned in the production of disease. The non-pathogenic varieties (those incapable of producing disease) are of a purely saprophytic nature—that is, they exist upon dead matters—either vegetable or animal.

"The rôle played in nature by the saprophytic bacteria is a very important one. Through their presence the highly complicated tissues of dead animals and vegetables are resolved into the simpler compounds, carbonic acid and ammonia, in which form they may be taken up and appropriated as food by the more highly organized members of the vegetable kingdom. It is by this ultimate production of carbonic acid, ammonia, and water by the bacteria, as end-products in the processes of decomposition and fermentation of the dead animal and vegetable tissues, that the demands of growing vegetation for these compounds are largely supplied.

The chlorophyl plants do not possess the power of obtaining their carbon and nitrogen from such highly organized and complicated substances as serve for the nutrition of the bacteria, and as the production of the simpler compounds (CO_2, NH_3, H_2O) by the animal world is not sufficient to meet the demands of the chlorophyl plants, the importance of the part played by the bacteria in making up this deficit cannot be overestimated. Were it not for the activity of these microscopic living particles, all life upon the surface of the earth would certainly cease. Deprive higher vegetation of the carbon and nitrogen supplied to it as a result of bacterial activity, and its development comes rapidly to an end. Rob the animal kingdom of the food-stuffs supplied to it by the vegetable world, and life is no longer possible.

Were it not for the presence of these saprophytic forms, the surface of the earth would in course of time be strewn with the remains of dead animals and vegetables.

Another group, the water bacteria, are perhaps instrumental in bringing about favorable changes in polluted waters. Still others are concerned in the production of changes in the soil which favor the life of higher members of the vegetable kingdom.

It is plain, therefore, that the saprophytes, which represent by far the large majority of all bacteria, must be looked upon by us in the light of benefactors, without which existence would be impossible.

With the parasites, on the other hand, the conditions are far from analogous. Through their existence there is constantly a loss, rather than a gain, to both the animal and vegetable kingdoms. Their host must always be a living body in which exist conditions favorable to their development, and from which they appropriate substances which may be necessary to the health and life of the tissues of the organism to which they may have found access. At the same time the substances which they form as products of their nutrition may be direct poisons for surrounding tissues.

In their relations to humanity the positions occupied by the two biologically different groups, the saprophytes on the one hand and the parasites on the other, are directly opposite; the saprophytic forms standing in the relation of benefactors, in resolving dead animal and vegetable bodies into their component parts, which serve for food for living vegetation, and, at the same time, removing from the surface of the earth the remains of all dead organic substances; while the parasitic group exists only at the expense of the more highly organized members of both kingdoms. It is to the parasitic group that the pathogenic organisms belong. ("The Principles of Bacteriology," Abbott, pp. 23 and 24).

As has been said, bacteria, as a rule, are found in the air deposited upon dust particles, and it follows, therefore, that where dust is most abundant, there bacteria are likely to be present in largest numbers. This dust, if found in the open streets or ordinary dwelling houses, is not of necessity dangerous because of the bacteria associated with it; but if it is found in the apartments of a patient suffering from some infectious malady, it can hardly be considered as of such an innocent nature. Recent experiments show that infection may be carried by the dust of apartments occupied by persons suffering from infectious diseases. Especially is this the case with the dust of rooms occupied by consumptives, and particularly so when they are not cleanly in their habits. Here the expectoration, in which the organism causing the disease may always be found, is not unfrequently allowed to dry upon the napkins, handkerchiefs, or clothing of the patient, or when it finds its way to the floor, it may be ground up with the dust into powder by the feet of those walking about the room. In this form it may readily become suspended in the air and be inhaled by other occupants of the apartment. The frequency of the pulmonary form of consumption can most probably be explained in this way. The organisms causing erysipelatous inflammations have been found in the dust from beneath the floor of a room occupied by persons suffering from erysipelas.

The pyogenic micrococci (the organisms giving rise to abscesses and other pus formations) are not uncommonly present in the air of apartments occupied by patients suffering from suppurative troubles.

It is safe to say that under normal conditions the chances of finding disease-producing organisms in the air of apartments are not very great. If, however, the apartment be occupied by patients undergoing treatment for infectious troubles, their demonstration may be possible, more particularly in the dust, but where cleanliness and the prevention of the accumulation of dust is carried out, the air may be kept practically free from bacteria.

To recapitulate, the alterations experienced by the air of over-crowded, poorly ventilated apartments, as a result of life processes, are:

(1.) A slight diminution in the amount of oxygen.

(2.) An increase in the amount of carbonic acid, and along with it the organic pollution resulting from the decomposition of perspiration and epithelium on the surface of the body, and from gastric and intestinal digestion and decomposition.

(3.) Elevation of its temperature and addition of moisture.

(4.) The addition of solid particles, upon which may be deposited either innocent or disease-producing bacteria, for the most part the former.

We will now consider, briefly, some of the impurities of air due, not to respiration or to cutaneous exhalation or exfoliation, but to certain conditions connected with human habitations or occupations, including sewer air, soil air, offensive and dangerous gases due to various processes of manufacture, and dusts of the same origin.

Sewer air, including not only the air of sewers properly so-called, but the air of house drains and cesspools, has been the subject of much literature and of many discourses during the last 40 years, and the dangers of "sewer gas," as it has been called, have been brought to the attention of the public so frequently and so forcibly as to have produced in many places special laws and municipal regulations with regard to house drainage.

The origin or spread of between 30 and 40 different diseases, including small pox, scarlet fever, measles, malaria, diphtheria, typhoid, inflammations of the ear, eye, throat, etc., dyspepsia, diarrhœal affections, coughs, colds, lung diseases, liver affections and skin troubles has been from time to time attributed to this so-called "sewer gas," and much labor has been expended in efforts to isolate this poison and determinine its composition and properties. We are now fairly well acquainted with the composition of the air found in sewers,

and know that there is no such thing as a distinct and peculiar sewer gas. The air of ordinary sewers and house drains is ordinary atmospheric air, mixed with a relatively small amount of gases and vapors due to decomposition of sewage and also containing micro-organisms suspended in it, which are, as a rule, the same as those contained in the air of streets, but in less number for a given volume of the air. The products of the decomposition of sewage are carbonic acid, light carburetted hydrogen, sulphuretted hydrogen, ammonium sulphide, ammonium carbonate and volatile organic matters, the precise character depending not only on the composition of the sewage itself, which varies greatly, but on the nature of the micro-organisms at work, which depends on the proportion of oxygen present. In closed cesspools and privy vaults and in foul sewers of deposit, which are practically elongated cesspools, these products may accumulate to such an extent that the mixture produces insensibility and asphyxia in those who enter it and may rapidly cause death, while in somewhat less concentrated form they cause nausea, diarrhœa and general prostration and languor.

The air of sewers is also liable to become contaminated with illuminating gas passing in through the soil from leaky gas pipes in the vicinity, and ultimately producing a mixture which will explode if a light is brought into it, but this is, of course, exceptional. The air of an ordinary modern, fairly well constructed and ventilated sewer appears to differ from the street air chiefly in having a higher proportion of carbonic acid. Thus Professor Nichols reports as the result of a large number of analyses of the air in a six-foot brick sewer 3,500 feet long, with four perforated manholes at intervals, that the proportion of carbonic acid ranged from 8.65 to 23.95 volumes in 10,000 of air, the higher proportion occurring in the warm months. This was a tide-locked sewer, and the ventilation was poor. In a paper on the air of sewers published in the Proceedings of the Royal Society of London, Vol. XLII., 1847, p. 51, Carnelley and Haldane give the results of a number of examinations of sewer air from London and from Dundee sewers, in which the carbonic acid, the organic matter and the number of micro-organisms were determined. They found that the amount of CO_2 was about twice, and of organic matter about three times as great as in the outside air at the same time, but that the number of micro-organisms was less, that as regards quantity of the three constituents named the air of the sewers was in a very much better condition than that of naturally ventilated schools, and that with the notable exception of organic matter, it had likewise the advantage of mechanically ventilated schools.

A special attempt was made to separate any poisonous volatile organic bases in the air such as ptomaines, but without success. The majority of the micro-organisms found come from the outside air, and the greater the proportion of carbonic acid the fewer of these organisms are found. Where splashing occurs in the sewer the number of micro-organisms in the air increases.

Essentially the same results have been obtained by other investigators making bacterial analyses of air. Specific pathogenic micro-organisms have not been found in the air of sewers, and if the sewers are properly constructed and ventilated, there seems to be little or no danger in remaining in them for several hours. As regards house drains and soil pipes, the condition of the air in them depends greatly upon whether they are properly ventilated or not. So long as the fixtures connected with them are in daily use these pipes are lined with a moist slimy layer of organic matter, in which bacteria of various kinds grow in immense numbers. If the supply of air is abundant, these bacteria are mostly aerobic and the substances produced by their action are, as a rule, odorless, and are rapidly carried away, by the air current, if gaseous, by the next flush of liquid, if soluble.

As bacteria are not given off to the air from fluids or moist surfaces, few micro-organisms are to be found in soil pipe air, and those are brought in from the external air.

It will be seen that the probabilities of the conveyance of the germs of specific diseases through sewer or soil pipe air under ordinary circumstances are very small, and there is very little evidence that any diseases have been thus conveyed, with the exception of those due to the micro-organisms which produce suppuration. In hospitals, before the introduction of antiseptic methods of treatment of wounds, the pyogenic organisms were of course very numerous in the hospital drains, and there are several cases in which localized outbreaks of erysipelas and unhealthy wound action appeared to be connected with the passage of the house drain air into the ward.

A sufficient number of cases of pyogenous diseases occurring in persons occupying, in the autumn, houses which had stood empty all summer have also been reported to make it probable that when the traps become empty and the soil pipes dry, some infectious dusts may have been borne into the rooms.

Distinguished English sanitarians believe that typhoid fever has been spread through the gases coming from foul sewers, and I do not deny the possibility, but I know of no satisfactory evidence of such an occurrence. Diphtheria and typhoid are diseases which

prevail more extensively where there are no sewers than in the sewered part of the cities, even where the sewers are badly constructed.

While I do not attach much importance to sewer air as a means of transmission of specific disease, I believe that its continuous inhalation is dangerous, owing to the large amount of volatile organic matters which it contains, and that for this reason, as well as to prevent the formation of explosive mixtures and of unpleasant odors, continuous ventilation should be provided for all sewers, house drains and cesspools. The methods of doing this will be described hereafter.

Another source of atmospheric pollution is the ground. Though the air of the soil is primarily the atmospheric air that, through processes of diffusion and pressure has entered the pores of the earth, still as we find it there it has undergone such manifold changes in its chemical composition that it can hardly be recognized. The most conspicuous of these changes result from the activity of countless living micro-organisms that are present in the superficial layers of the earth's surface. Their function is mainly the decomposition of highly complicated organic compounds into simpler forms in which condition they may be taken up and appropriated as nutrition by higher plants. In performing these functions much of the oxygen of the air is used up by the bacteria, and one of the conspicuous alterations that atmospheric air is seen to undergo in the ground is a marked diminution in its normal amount of oxygen. At a very short distance below the surface the reduction in the amount of this gas has produced a proportion as low as 7.4 parts per 100 of air, instead of about 21 parts per 100 as seen in the atmosphere. The proportion of oxygen thus lost is used up by the micro-organisms in processes of fermentation and decomposition and appears again in the products of these processes, and we find that carbonic acid is always present in the soil air in greater amounts than in the free atmosphere, and usually in much greater amounts. As a result of many analyses made upon the air of the ground, carbonic acid is found to be present in amounts varying from 0.2 per cent. to 14.0 per cent. instead of 0.04 per cent. as in the normal atmosphere. Pettenkofer believes the fluctuations in the amount of the gas in the soil to be more or less parallel with fluctuations in temperature, and Möller & Wallney state that the largest amounts of carbonic acid are found in soils that are rich in organic matter, moderately moist, of a suitable temperature and to which air has free access.

Another gaseous constituent of ground air that appears as a result of decomposition and fermentation is ammonia. This compound is

usually present, but in the form of free ammonia in only very small amounts. Fodor, as a result of many analyses, found free ammonia in air from the soil to the extent of only 0.000048 to 0.000082 grains in 100 litres of air.

Sulphuretted hydrogen can also at times be demonstrated in ground air. It, too, appears as a product of decomposition of organic substances, and now and then as a reduction product from salts of sulphuric acid (Soyka). In addition to these commoner gases of decomposition, some of the carbon compounds have been found in ground air by Nichols, and Hoppe-Seyler mentions the development of methane in a piece of ground saturated with moisture.

Moisture in the soil is so essential to decomposition and nitrification that without it these phenomena cannot occur, for in the dry state the living organisms cannot perform their functions.

On the other hand, too much moisture, complete saturation, is also quite as much of an obstacle to the existence of these processes as no moisture at all. It is in ground that is alternately wet and dry, speaking loosely, that the organisms find the most favorable conditions for their biological activities, and it is in just such soil as this that the ordinary gaseous products are found in greatest abundance. It is this character of ground that makes up the greater portion of the earth's surface.

It is impossible to give a fixed formula for the air of the soil, because of the great variations that are seen to occur in the relative proportion of its constituents in air taken from the soil of different localities. Analyses made of air from points in the ground, closely located the one to the other, will often demonstrate striking differences in composition.

In general, it may be said that the air of virgin soil is more constant in its composition, and freer from offensive and perhaps harmful ingredients, than the air from soils round about the habitations of man.

This difference is not difficult to understand if one compares the conditions found in virgin, unoccupied soil with those seen in the ground upon which great cities are built. Permeated, as the latter is in all directions by gas mains and sewers that are frequently leaky, contaminated at many points by decomposing waste products and human excrement, we would expect to find a condition of the soil air quite in contrast with that of ground not so polluted, and so we do. If, in addition, it is remembered that each house built upon such soil acts the year round as an aspirator for the air of the ground upon which it stands, the advantages to be gained by proper attention to the sanitary condition of the ground are plain. The air thus drawn from

the soil into houses not only contains gaseous ingredients which may or may not be deleterious to health, but it is wanting in oxygen, the element most essential to the healthy performance of our bodily functions.

As to the presence of bacteria in the air of the soil, it suffices to say that analyses of air drawn from the soil under proper precautions, show it to be free from living organisms. Though bacteria are present in countless numbers in the upper layers of the soil itself they are nevertheless held there, being deposited in the finer pores, and caused to adhere through the moisture that surrounds them.

Under normal conditions they are not found at a depth greater than 1½ meters (C. Fraenkel), and, as said, have not been detected in the air from the ground.

OFFENSIVE GASES.

The gaseous pollutions arising as a result of the industries, can hardly be considered in relation to the air of private apartments, except perhaps of those situated in the immediate vicinity. For, as pointed out, the diffusion and mixing of gases in the atmosphere due to the action of the winds, is so rapid, that only in exceptional instances can the polluting matters be detected. They are rapidly swept away from their source by the air currents and quickly diluted to a point that renders their detection a matter of considerable difficulty.

In the immediate neighborhood of certain industries, gases, characteristic of the work in progress, may, under favorable atmospheric conditions, sometimes be detected.

In some instances the pollutions have only the effect of diluting the oxygen in the air, they themselves having no deleterious action whatever and being generally considered as physiologically neutral or indifferent substances. For example, the excess of hydrogen and "choke-damp," found in the air of mines, is of more significance in diminishing the ratio of oxygen in the air breathed than of producing, *per se*, any direct, definite effect upon the health of those inhaling it.

On the other hand, from certain of the industries where products, chemical in nature, are manufactured, or where they are of such a composition that large quantities of chemical agents are employed in their production, gases of a deleterious nature are not uncommonly thrown off into the atmosphere.

The gaseous waste products of some of the industries as given by Parkes, are :

Hydrochloric acid gas from alkali works.

Sulphur dioxide and sulphuric acid, from copper works.

Sulphuretted hydrogen, from several chemical works, especially from ammonia works.

Carbon dioxide, carbon monoxide and sulphuretted hydrogen, from brick and cement works.

Carbon monoxide (in addition to above cases), from iron furnaces, may amount to as much as 22 to 25 per cent.; from copper furnaces, 15 to 19 per cent.

Organic vapors, from glue refineries, bone burners, slaughter houses and knackeries.

Zinc fumes, from brass founderies.

Arsenical fumes, from copper smelting works.

Phosphorous fumes, from match factories.

Carbon disulphide, from India-rubber works.

From this list it may be seen that the most of these waste products are not only of an offensive character, but are actually irrespirable in their nature; producing in some instances irritation of the air passages in others direct systemic poisonous effects.

As directly poisonous products of the industries carbon monoxide, sulphureted hydrogen and the compounds of carbon and sulphuric acid may be mentioned, less frequently arseniureted and phosphureted hydrogen, and the vapors of iodine and of bromide may be detected.

This is hardly the place to enter into a discussion upon the gaseous waste products from special industries; it suffices to say that round about the most of them, certain of the above-mentioned compounds may be detected, the amount present depending, of course, upon the rate of production and the efficacy of the arrangements for their removal or destruction.

It is safe to say that the greater influence upon health from the respiration of these gases is experienced by those immediately engaged in the manufactories, and, unless favored by particular conditions of wind and weather, in most instances the presence of the gases in the open air is not recognized by persons outside the walls of the factories in which they are produced.

For their removal from the work-rooms, special arrangements are made, which will be referred to hereafter.

In the free atmosphere, the presence of dust to any considerable amount, is only an intermittent and temporary occurrence, so that its significance here is of but little importance.

In the industries, however, where the employees are exposed constantly to the dust-laden air, its inhalation is seen to result in certain

important changes in the tissues of the lungs and lymphatics. These changes, in many instances, are characteristic of the trade followed by the person affected.

Most conspicuous among the tissue changes resulting from the inhalation of fine solid particles are those seen in the lungs of miners, or men whose work necessitates the constant handling of coals, stokers, coal dealers, etc. Here the coal, as such is deposited in the tissues. In the case of chimney sweeps, the carbon is found in a more finely divided form, as soot. In moulders and lead-pencil workers, it is deposited as graphite.

So common is this deposit in the lungs of miners, stokers, etc., that the condition is always expected. It is known commonly as "miner's lung," *anthracosis* being the medical term for the same.

Siderosis is the term employed to designate a condition of the tissues, more particularly of the lungs, commonly resulting from the inhalation of iron or steel in a finely divided form.

In the lungs of grinders, file makers, smiths, potters, millers, glass polishers, wool, cotton and wood workers, tissue changes traceable to the dust of the trade followed by the individual, are constantly to be found after death.

Without going into the details of the different pathological processes set up in the lungs by the various forms of solid matters which may be inhaled, it will suffice to say that in general there appears primarily a bronchial catarrh, followed by emphysema. In some cases interstitial changes in the lungs occur, rendering the tissues hard, inelastic, and incapable of performing their proper function (cirrhosis of the lung). It is plain that a lung thus hampered in the performance of its natural function offers less resistance to the invasion of actually infective or disease-producing agents than it otherwise would.

Many observers believe in the existence of a relation between pneumonia and dust inhalation. Likewise pulmonary phthisis is frequently attributed to this cause.

There appears to be some difference in the hygienic significance of the different dusts; by some it is claimed that pulmonary consumption is less frequent in workmen who inhale the dust from animal and vegetable matters than in those inhaling metallic and mineral particles. It is a well-established fact that poisonous results are observed among the hands employed in lead, chrome, mercury, arsenic, phosphorus and zinc works.

Whether these results are due to inhalation of these substances in finely divided form or to the uncleanly habits of workmen who partake

of their meals without sufficient attention to the toilet, is difficult to say, as the data at hand are not of sufficient amount to justify positive opinion.

Hesse, in his work, endeavors to establish a relation between the amount of dust present in a given volume of air and the nature of work from which this dust is given off. As a result, he found per cubic meters of air:

175	Milligrams	of dust in	felt works.
48	"	"	an old mill.
4	"	"	a new mill.
3	"	"	weaving mill.
9	"	"	sculptor's studio.
4-25	"	"	paper mill.
72-100	"	"	iron factory.
14	"	"	coal mine.
14	"	"	iron mine.
0	"	"	a dwelling room.

These results must be accepted as liable to the greatest fluctuation with varying conditions. Their principal value is to illustrate the average relation between the proportion of dust in the air of different manufacturing establishments.

The pulmonary consumption commonly attributed to the inhalation of dust, is not due to the action of the dust particles themselves, but to the specific infective factors of the disease which they carry into the air passages.

It is true, as said, that these irritating particles, even without the aid of living organisms, certainly lessen the resisting powers of the tissues by bringing about catarrhal troubles, but of themselves they are not capable of establishing without aid the condition known as consumption. We know now that this disease depends for its existence upon the presence of a living organism in the tissues—the *bacillus tuberculosis*—we know, moreover, that this organism is thrown off in the expectoration of tuberculous subjects.

In nearly all workshops, mills and factories it is safe to expect a certain number of sufferers from this disease. Where no provision against the spread of the disease, in the way of proper receptacles into which these people must expectorate, are made, the expectoration usually is upon the floor; it becomes dried and is ground up with the dust by the feet of passers by and enters the air in the form of finely divided particles, and is inhaled by those engaged in the apartment. In this way it is fair to assume that a certain amount of infection is constantly taking place.

So long as surfaces are moist, it is impossible for bacteria to arise from them into the air. If, therefore, in the case of workshops in which a large number of hands are employed, provision be made by which the expectoration shall conveniently find its way into receptacles containing water, there is nothing to be feared, provided these receptacles are properly disinfected at regular intervals.

In late years many devices have been suggested for diminishing the danger to workmen from this source. Some of these aim at lessening the amount of dust thrown into the air by the employment of moisture in the work, or by causing grinding, pulverizing, etc., to be done in closed chambers—others, where such measures are not practicable, endeavor to rid the air of its dust by ventilation, while others aim at personal protection of the workmen by requiring them to wear a filtering mask.

Where such measures are intelligently carried out, they result in a decided improvement in the well-being and comfort of the individuals affected by them.

As is shown in Chapter VI., on moisture in its relations to ventilation, we require air to remove bodily heat as well as to supply oxygen—and ventilation is necessary to provide for the evaporation of the water from the lungs and skin, by which a considerable part of this cooling is effected. It is also required to remove moisture from damp walls, from wet clothing, and for various purposes in the arts and manufactures in which it is desirable to dry more or less thoroughly certain tissues or other articles. In his very charming popular lectures on the relations of the air to our clothes and houses, Professor von Pettenkofer has shown the importance of porous building materials in the walls of inhabited rooms, and the desirability that these pores should be filled with air and not with water. In his typical house, built with 100,000 bricks, he calculates that the walls of the newly-built house will contain about 10,000 gallons of water which must be removed by evaporation to make the building healthy. Assuming the average temperature of the air to be 50° F., and that its hygrometric condition is that of 75 per cent. of full saturation, each cubic foot of air is capable of taking up about one additional grain of water, or about 700 millions cubic feet of air are required to dry the building in question.

The process may be hastened by raising the temperature, and this is what is often done in new buildings to make them sooner ready for occupancy. If, for instance, we heat air at 50 degrees, with 75 per cent. of saturation, up to 70 degrees it will take up over 4 grains of water instead of 1 to each cubic foot, while at the same time the move-

ment of the air will be increased, and a much larger quantity passed through the house, so that it may be dried in one-twentieth of the time that it would be required if it were left unheated.

In drying rooms, or kilns, or cases, the object is to remove the superfluous moisture by means of heated air. For thin stuffs such as muslin or paper the drying may be effected by passing them over heated metal cylinders freely exposed to the air—but as a rule it is produced by placing them in a closed space heated by metal pipes, usually in this country, steam pipes. A proper supply of air is necessary for this purpose and the quantity required depends on the amount of moisture to be removed, the amount of moisture in the air when it comes in contact with the heating apparatus, the amount of heat communicated to it, and the time which is to be allowed for the operation. The heating surfaces may be placed in the space with the articles to be dried, as is usually done in laundry drying rooms, or they may be placed outside and have the air forced through them into the drying room by means of a fan or blower, or drawn through them by means of an aspirating fan or chimney. For thick articles a longer time and lower temperatures are desirable than for thin ones. Tredgold's rule is that "the most economical rate of drying will be, when the quantity of moisture evaporated in a given time is 0.08 times the whole quantity the goods contain; and the time each piece will have to remain in the drying room will be about 30 times the given time." If, for instance, the goods are to be dried in 30 minutes, then the apparatus should be competent to remove 0.08, or about one-twelfth of the total original moisture in one minute. He thinks that the heat most desirable to attain in the drying room is 90° F. when the dew point of the external air is 40 degrees. Under these circumstances he found that nine grains of water might be evaporated per minute from a square foot of surface of cotton cloth, which is a cubic foot of water per minute from 2,700 square yards of cloth, and recommends the allowance of 30 cubic feet of air per minute for each square yard of cloth, or for a piece of 25 yards, 750 cubic feet. For this purpose he allows 270 square feet of radiating surface of steam pipe to effect the drying in 20 minutes, or one-third of this amount to effect the drying in an hour, and the areas of opening for entrance and exit of air should be about 1½ square feet. Hood allows from 15 to 20 square feet of surface of hot-water pipes to 100 cubic feet of space in common drying rooms, which in the English climate will heat the room to about 120 degrees when the room is empty and no change of air is made He states that the temperature falls from 15 to 20 degrees when ventilation is going on, and that when

the room is filled with wet clothes the temperature falls to 80 or 90 degrees. He gives no data as to air supply although he rightly says that ventilation in such cases is far more important than the degree of heat maintained in the room. In the drying rooms of ordinary steam laundries, as constructed at present, either no provision at all is made for the entrance and exit of air or it is totally insufficient, the result being great waste of heat and prolongation of the time required to effect desiccation. The rule-of-thumb allowance of steam-fitters appears to be about 1 square foot of pipe surface to 5 cubic feet of space. In his book on steam heating Mr. Baldwin devotes a chapter to drying by steam heat in which he lays stress on the fact that direct radiation from surfaces at high temperatures is the most economical method, but says nothing about the quantity of air required. There is no doubt that the hotter the drying room the less time is required—but there is also no doubt that for most purposes a temperature above 130° F. is not desirable in a drying room and this will fall to 90° F., while active evaporation is going on. If insufficient air to carry off the vapor be admitted much of the effect of the heat is lost, for when the air is thoroughly saturated and the mixture of air and vapor has been heated up to the capacity of the plant, no more vapor will be absorbed.

The following table shows the number of grains of water per cubic foot which air at various temperatures is capable of taking up without producing visible vapor:

Degrees Fahr.	Grains per Cubic Foot.	Degrees Fahr.	Grains per Cubic Foot.
10	1.1	70	7.94
15	1.31	75	9.24
20	1.56	80	10.73
25	1.85	85	12.43
30	2.19	90	14.38
35	2.59	95	16.60
40	3.06	100	19.12
45	3.61	110	25.5
50	4.24	120	34.
55	4.97	130	42.5
60	5.82	140	57.
65	6.81	...	.....

Mr. Baldwin remarks that an increase of about 25 degrees in the temperature of the air doubles its capacity for taking up moisture, and hence, other things being equal, an increase of 25 degrees in the temperature of a drying room will reduce the time for drying one-half.

Mr. Box gives as the result of experiments the following figures as regards the heat required to evaporate one pound of water at temperatures below the boiling point from open vessels exposed to air at 52° F., and humidity, 86:

Temperature of the Water.	Number of Thermal Units Required to Evaporate 1 Pound of Water.	Temperature of the Water.	Number of Thermal Units Required to Evaporate 1 Pound of Water.
62°	2,750	142°	1,450
72°	2,500	172°	1,284
82°	2,280	202°	1,203
92°	2,080	212°	1,186
102°	1,910	....	.....

In rough calculations we may assume that to evaporate a pound of water 1,500 thermal units are required, and that one thermal unit will heat 50 cubic feet of air 1° F., hence to evaporate 100 pounds of water by air heated from 60 to 130 would require $150{,}000 \times 50 \div 70 = 107{,}143$ cubic feet of air to convey the heat. If this air is capable of taking up 7 grains of water per cubic foot from the moist surfaces, it would require 100,000 cubic feet of air to take up 100 pounds of water, and it would be better to allow 1,500 cubic feet of air to each pound of water to be removed, to which air at least 1,500 thermal units of heat must be communicated.

In this connection the following data with regard to the drying room of the laundry of the Johns Hopkins Hospital in Baltimore, for which data I am indebted to the Superintendent, Dr. Hurd, will be of interest:

The dry room is 9 feet 6 inches wide by 22 feet long by 9 feet high, and contains 1,881 cubic feet. It is heated with 27 coils of 1-inch pipe, 9 feet long by 4 pipes high, which gives 324 square feet of radiating surface There are 25 racks 9 by 9 feet, 2 inches thick when filled with clothes, which gives 337 cubic feet. The air is supplied through 50 1¼-inch holes (two near the bottom of each rack), each of which supplies about 80 feet per minute. The exit for the air is through a 12 by 14 register into the vent shaft. The temperature of the air coming through this register is 42° C. (107.6° F.) when the dryer is filled with clothes.

With 55 pounds of steam pressure at the boiler, the temperature of the room when empty is 72° C. (161.6° F.); when filled with wet clothes it falls to 56° C. (132.8° F.)

It takes from 30 to 40 minutes to dry unstarched clothes, and about ten minutes longer for starched ones.

With 45 pounds steam pressure at boiler, and a temperature of 70° C. in the empty dryers, 10 wet sheets weighing 22½ pounds were placed on the racks. In 20 minutes the sheets were dry, weighing 15 pounds, and the temperature in the dryers was 65° C. After these sheets were passed through the mangle they weighed 14½ pounds.

One flannel skirt, containing two square yards, on coming from the wringer weighs 2 lbs. 2 oz.; on coming from the dryer 1½ pounds.

One spread, containing 5⅓ square yards, coming from the wringer weighs 5 pounds; from dryer, 3¼ pounds; from mangle, 2½ pounds.

One bleached sheet, containing 5⅓ square yards, coming from wringer, weighs 3 pounds; from dryer, 1¾ pounds; from mangle, 1½ pounds.

One blanket, containing 3½ square yards, coming from wringer, weighs 4 pounds; from dryer, 2½ pounds.

The following data are furnished from the laundry of the Hospital of the University of Pennsylvania:

	Wet.	Dry
6 blankets	17 pounds, ½ ounces.	12 pounds, 12¼ ounces.
6 spreads	12 " 13 "	8 " 13½ "
6 sheets	12 " 13½ "	8 " 12¾ "
6 shirts	6 " 8½ "	5 " ¼ "
6 pillow cases	2 " 12 "	2 " 1½ "
6 towels	1 " 14¼ "	1 " 8 "

In this laundry, the steam pipes form a flat grating near the floor and the supply of air is very small except by leakage. In one trial, on a clear day, external temperature, 60° F., 72¼ pounds of water were evaporated in 90 minutes, the temperature before putting in the wet clothes being 144 degrees; immediately after filling, 90 degrees; in five minutes, 99 degrees; in 20 minutes, 114 degrees; in 40 minutes, 120 degrees; in 60 minutes, 125 degrees, and in 90 minutes, 132 degrees.

In another trial, on a cold, raw day, with rain, 24 sheets, 18 blankets, 24 spreads, 45 pillow cases, 24 night shirts and 72 towels, weighing, while wet, 247¼ pounds, were placed in the drying room, which was then at a temperature of 146° F. In five minutes the temperature was 100 degrees; in 20 minutes, 115 degrees; in 35 minutes, 120 degrees, and in 90 minutes, 132 degrees. The clothes were then taken out and

found to weigh 157¾ pounds, showing that 89½ pounds of water had been evaporated in 90 minutes. In each case the steam was at 70 pounds pressure. With a proper arrangement of the radiating surface and sufficient air supply, this amount of work should have been done in less than half the time actually occupied.

The following data in regard to drying rooms were kindly furnished by Messrs. Bartlett, Hayward & Co., of Baltimore. "The drying kiln for lumber of A. H. Andrews & Co., of Chicago, has a capacity of 24,000 feet pine boards; the size of the room is 17′x52′x12′ in clear heights; the heating surface is 8,000 feet 1-inch pipe, the steam pressure 80 pounds per square inch; there are eight vents 8″x8″; the time required for drying is five days. The kiln of R. B. Andrews, of Baltimore, brick dryers, has a capacity of 25,000 bricks; the size of the room is 15′x110′x8′, the heating surface 11,000 feet of 1-inch pipe; the time required to dry the bricks ready for burning is 24 to 72 hours, according to kind of clay. The heat has to be graduated to suit the quality of the clay; generally the temperature is quite low at first until the bricks are heated through, then the temperature is gradually raised before any air is admitted."

It becomes at times very necessary to entirely change the air in an enclosed space in order to prevent the formation, or the removal if formed, of an explosive mixture of gases, or of a collection of gas not explosive, but dangerous to life. This may occur, for example, in a petroleum tank steamer when the oil has been pumped out. A considerable quantity of gas from the residual fluid accumulates, and by mixture with the atmospheric air by the process of diffusion a mixture is formed which the introduction of a light will cause to explode with great violence. This accident has occurred several times. As examples of the accumulation of carbonic acid to such an extent as to make the air irrespirable, may be taken the case of large brewing vats when emptied of their liquid contents—or of certain deep cesspools, or of wells where the deep-ground air contains a high proportion of the gas.

In the case of explosive mixtures, what is required is mechanical ventilation by means of a fan so arranged with a movable duct, that the whole of the room or tank can be thoroughly flushed out. In the case of foul or irrespirable gases not explosive, mechanical means may also be used in the form of a sort of extemporized pump, in which an umbrella may be made the piston, but in these cases it will often be found more convenient to use heat by burning a bundle of straw or shavings, to secure an upward current.

CHAPTER VI.

ON MOISTURE IN AIR, AND ITS RELATIONS TO VENTILATION.

THE relations of atmospheric moisture to health and comfort are interesting and important in connection with arrangements for ventilation and heating. These relations depend in part on the influence which the proportion of humidity in the surrounding air has on the evaporation of moisture from the air passages and external surface of the human body, and in part on the peculiar relations which exist between the exhaled watery vapor and the volatile organic matter escaping from the lungs.

A healthy man of average size in the course of 24 hours transforms into actual energy from the potential energy which has been supplied to his tissues in the form of food, an amount equal to about 3,400 foot-tons, of which about 300 foot-tons is the amount of muscular force exerted in a good day's work, 260 foot-tons is the amount of visceral work done by the heart, the muscles of respiration, the glands, etc., and 2,840 foot-tons appears in the form of heat. The visceral work also appears ultimately as heat, just as the work going on in a watch that is running raises its temperature.

Another way of stating it is that the heat income of the body due mainly to oxidation of hydro-carbons amounts to from 2 to 2¾ millions of calories daily, depending upon age, sex, amount of exercise, diet, etc. All this energy is set free as mechanical labor and as heat.

Of this heat, 192,060 calories are expended in evaporating 330 grammes of water from the lungs, and 384,120 calories in evaporating 660 grammes of water from the skin—that is, about 23 per cent. of the heat is used in this way, while about 72 per cent. is radiated and conducted from the skin, and the remainder is lost in heating the air inspired, and the excretions from the bowels and kidneys.*

If this heat is not gotten rid of promptly and regularly, discomfort is soon produced, and it will be seen from the above figures that the greater part of it goes through conduction and evaporation. The

* Landois' Human Physiology. London, 1888, p. 332.

rapidity with which evaporation goes on, depends on the capacity for taking up moisture possessed by the surrounding air, and this depends upon its temperature and the amount of moisture which it already contains.

Air that is loaded with moisture transmits, in each unit of time, much more heat than air which is dry. Hence, when air at a high temperature is saturated with moisture, it communicates heat to the body, producing an oppressive sensation, but when the temperature of the saturated air is lower than the temperature of the body, the transfer of heat goes on rapidly from the body to the air and produces a sensation of cold. A low temperature with a dry atmosphere is, therefore, more comfortable than a higher temperature when the air is loaded with moisture.

At and below the freezing point air contains so little vapor that it may be called dry. Air completely saturated with moisture at temperatures of from 35°F. to 45°F. removes heat rapidly from the surface of the body, not so much by evaporation as by conduction, and is felt to be very chilly.

At temperatures of between 55°F. and 65°F. moist air is felt as very comfortable, neither too hot nor too cold, while above 70°F. a saturated atmosphere feels sultry and oppressive, and if the temperature be above 90°F. it becomes exhausting. On the other hand, dry air at temperatures of from 32°F. to 80°F. is not specially uncomfortable if proper clothing be worn, and is certainly not injurious to health.

At Fort Yuma, California, which used to be famous as the hottest military post in the United States, during the months of April, May and June, when no rain falls, with the thermometer at 100°F., or even at 112° F., the skin becomes dry and hard, the hair crisp, furniture falls to pieces, newspapers must be handled carefully or they will break, and a No. 2 lead pencil leaves no more trace on paper than a piece of anthracite—yet under these conditions, lasting for weeks, there is no special increase in sickness.

Dr. Wyman states that the Harmattan, a wind which blows from the scorching sands of Africa, drying the branches of trees, cracking doors and furniture, and drying the eyes, lips and throat, so that they are painful, is not an unhealthy wind ; on the contrary, its first breath cures intermittent fevers, and malarial affections disappear as if by enchantment. A dry air, with a uniform temperature, makes a healthy climate, as in New Mexico.

In general, dry climates, especially where the temperature is equable, are considered to be the most healthy. English authorities on

heating usually assume that the proper temperature of inhabited rooms should be about 62° F., while the American standard is 70° F., and, although these differences are partly due to habit, they are also, to a very considerable extent, due to differences in climate, and especially to the differences in the amount of moisture in the air.

If the air be at 32° F., and dry, a person loses by respiration 1,172 thermal units, and if the air be at 86° F., and quite dry, he loses 1,096 thermal units—the difference being only 76. But if the air be saturated with moisture at these two temperatures, he will lose at 32 degrees 1,062, and at 86 degrees, 420 thermal units—a difference of 640—which will make him feel very hot and uncomfortable. We need air for cooling almost as much as we do for the oxygen it contains—and the power which it has to convey away our surplus heat, depends greatly on its moisture (Pettenkofer).

When we turn to artificial climates, we find that in our houses in winter, with the external air at 32° F., the percentage of moisture is often between 30 and 40 without producing any discomfort.

There can be no better illustration of this than the results obtained by Dr. Cowles in the Boston City Hospital, and published by him in the report of the Massachusetts State Board of Health for 1879.

He says: "I believe that no discomfort has been felt or ill-effects produced from the low relative humidity, even on the occasions when there was only 15 to 21 per cent. of saturation. According to Dr. De Chaumont, so great dryness is inconsistent with a healthful condition of the atmosphere. Certainly, in this ward there is uniformly observed a remarkable absence of complaint of any kind that can be ascribed to the condition of the air, and a peculiar feeling of its freshness and purity is frequently spoken of by those who enter the room."

It is evident, therefore, that it is not necessary to supply moisture enough to heated air to bring the percentage up to 70. It is also to be noted that it will take about the same amount of fuel, or, in other words, will cost as much to furnish this percentage of moisture to air heated from 30° F. to 70° F., as it does to heat the air. Moreover, in a room properly ventilated under such circumstances, it would be practically almost impossible to maintain such a percentage of moisture, owing to the great rapidity with which the vapor of water diffuses in such dry air and the condensation which would occur on windows and thin outer walls. This whole subject has been well discussed by Mr. Robert Briggs, in a paper entitled, "On the Relation of Moisture in Air to Health and Comfort," published in the *Journal of the Franklin Institute* for 1878, and to this I would refer for further details.

In a paper on the "Theory of Ventilation," by Dr. De Chaumont, published in the *Proceedings*, of the Royal Society of London, Volume XXV., 1876–77, page 11, he concludes, from the result of his investigation, that "an increase of 1 per cent. of humidity has as much influence on the condition of air space (as judged of by the sense of smell) as a rise of 4.18 degrees of temperature in Fahrenheit's scale, equal to 2.32° C., or 1.86° Réaumur.

"This may be taken as a proof of the powerful influence exercised by a *damp* atmosphere, corroborating the conclusions arrived at by ordinary experience; and it follows that as much care ought to be taken to ensure proper hygrometric conditions as to maintain a sufficiently high temperature. This is especially the case in the wards or chambers of the sick, in which regular observations with the wet-and-dry-bulb thermometers ought to be made; these would probably give a valuable indication of the ventilation, either along with or in the absence of other more detailed investigations. Thus a room at the temperature of 60° F. and with 88 per cent. of humidity contains 5.1 grains of vapor per cubic foot; suppose the external air to be at 50° F., with the same humidity, 88 per cent; this would give 3.6 grains of vapor per cubic foot; to reduce the humidity in the room to 73 per cent., or 4.2 grains per cubic foot, we must add the following amount of external air:

$$\frac{5.1 \times 4.2}{4.2 \times 3.6} = 1.4$$

or once and a half the volume of air in the room. If the inmates have each 1,000 cubic feet of space, it follows that either their supply of fresh air is short by 1,500 cubic feet per head per hour, or else that there are sources of excessive humidity within the air space which demand immediate removal."

The effects produced in air by artificial heat, and which by some are supposed to be connected with insufficicnt moisture, are important, and merit more study than they have yet received.

Dr. Ure describes the effects of the use of highly-heated cockle stoves to be tension or fullness of the head, flushings of the countenance, frequent confusion of ideas, coldness of the extremities, and feeble pulse. Hood confirms this, and states that he examined a school heated in the same manner, and found it be so pernicious to the health of the children that they occasionally dropped off their seats in fainting fits. He goes on to say that "these pernicious effects, although generally in a somewhat less degree, always result from the use of intensely heated metallic surfaces. They are, however, much

modified if the air is tempered by the evaporation of water. In Russia and Sweden, and other places where close stoves are used, an earthen vessel of water is always placed on the stove for this purpose, and greatly mitigates the oppressive effects which would otherwise be experienced. The desiccating power of the air increases with the temperature to a very great extent. Air at 32 degrees contains, when saturated with moisture, $\frac{1}{160}$ of its weight of water; at 59 degrees it contains $\frac{1}{80}$; at 86 degrees it contains $\frac{1}{40}$; its capacity for moisture being doubled by each increase of 27° F.

Of the reality of the effects referred to by Dr. Ure and Mr. Hood, as resulting, in some cases, at all events, from heating air intended for respiration to a high temperature, there is no doubt, but that these effects are especially connected with the dryness of the air is not probable.

English writers usually state that, in order to secure health and comfort, the relative saturation with moisture of air to be respired should be from 65 to 75 per cent. Mr. Hood says that, "in rooms artificially heated, the most healthy state of the atmosphere will be obtained when the dew point of the air is not less than 10° nor more than 20° F. lower than the temperature of the room." Dr. De Chaumont states that for England the difference between the wet and dry bulb thermometers ought not to be less than 4 degrees nor more than 5 degrees, and that the percentage of humidity should not exceed .75, while Hood declares that we should endeavor to maintain in artificially heated rooms 82 per cent. of moisture. There is little doubt that De Chaumont is more nearly correct than Hood, so far as the English climate is concerned, but none of these figures will apply in the United States, as has been shown above.

But if it is not the dryness of the air which causes the disagreeable sensations whose frequency in furnace and steam-heated rooms no one can deny, what is it?

The answer is, that it is no single cause, but a combination of a number of causes. The first and most important is the want of sufficient fresh air to insure satisfactory ventilation. The amount of air required for this purpose, if admitted after passing through the heating chamber of an ordinary furnace, would soon make the room insufferably hot, for on a cold day its temperature from the common forms of apparatus will average 180° F. To prevent this, the register is usually partially or entirely closed as soon as the room becomes unpleasantly warm, and the fresh air is thus shut off as well as the heat.

The second cause is the contamination of the fresh heated air by gases from the furnace, and especially by carbonic oxide. This will be found to be the chief trouble in those cases where a dull, persistent headache, with the feeling as if an iron band were bound around the head, is produced, or in such cases as those mentioned by Ure and Hood.

From hot-air furnaces these gases pass mainly at the joints, and the more joints a furnace has the worse it is in this respect.

A very common cause of impurity in air heated either directly by furnaces or indirectly by steam or hot water, when the furnace is in the cellar, is leakage from the cellar into the cold-air flues or chambers. Brick piers, inclosing coils or radiators, are quite pervious to air, and the pipes or box flues used to bring fresh air to the heating surfaces leak very decidedly in the majority of cases.

A very common method used by servants for diminishing heat is to open the furnace door, and at the same time to obstruct the draught below. This gives rise to large volumes of carbonic oxide, some of which will almost assuredly escape into the cellar and it requires the presence of but a very small percentage of this gas to produce bad results.

The last cause of discomfort which need be mentioned here, is overheating in rooms which are occupied by a number of persons. In personal inspections in public offices, I have usually found the temperature to be between 75° and 80° F., to suit the sensations of the older and feeble clerks.

On a cold day the windows of an uninhabited room exert a temporary purifying influence on the air of the room by condensing the moisture, and with it a considerable quantity of organic matter, and the same effect is produced by the snow houses of the Esquimaux.

CHAPTER VII.

QUANTITY OF AIR REQUIRED FOR VENTILATION.

THE dimensions of flues and registers, the quantity of heating surface, and the amount of motive power required for the ventilation of a building or locality, depend upon the amount of fresh air that is to be supplied in a given time. It is in the determination of this amount that the young architect or engineer is likely to find his chief difficulties, owing to the great divergence of opinion among the authorities to whom he will probably refer for guidance.

As has been shown in the chapter on the history of ventilation, the figures for quantity of air per person per hour in assembly halls and hospitals were constantly increased by successive ventilators, but upon no definite principle or rule, until the introduction of the chemical method of testing the results. When it was found that the proportion of carbonic acid present might be, with certain precautions, accepted as a measure of the amount of offensive or dangerous impurity in the air, the next question was, how great a proportion of carbonic impurity, that is, of carbonic acid added to the air of a room by the respirations and exhalations of its inmates, is to be considered as permissible, or not undesirable or, in other words, as corresponding to what may be properly called good, or fair, or bad ventilation?

This question cannot be answered properly by considering the effects upon health produced by exposures to foul air for a few hours only, since these are rarely perceptible unless the impurity is very great.

It requires the observation of the effects on the health and life of a number of men exposed to such air for a series of months or of years, to demonstrate the slow but certain production of throat and lung troubles, the loss of energy and vitality and the shortening of life, which are thus produced. These observations have been made on soldiers occupying ill-ventilated barracks, and on operatives working in close work rooms, and comparison of the results has shown that, when in any room occupied by human beings there is a definite, unpleasant animal or musty odor, perceived by a person whose sense of

smell is of the usual acuteness and who enters the room from the fresh outer air, then continued breathing of the air producing such odor will be injurious to health.

The sense of smell is soon blunted, and after one has remained for 10 or 15 minutes in an ill-ventilated school or theater, he will probably not perceive any specially unpleasant odor, although he may feel hot and uncomfortable, and possibly have a slight headache as the result.

Careful observations have been made upon the relations between such odors as are referred to above and the proportions of carbonic acid present, and the results which are now generally accepted as authoritative, having been confirmed by subsequent observers, are those reported by Dr. De Chaumont. From a large number of experiments he obtained a series of data which he divides into five classes. In the first class the observer found no sensible difference in odor between the air of the room and that of the external air. In those in which the air is called "fresh" the temperature was about 63° F., the vapor and humidity 4.7 gr. per cubic foot, and the carbonic impurity due to respiration was 1.943 in 10,000 volumes. This shows satisfactory ventilation.

2. When the organic matter begins to be appreciated by the senses, and the air is said to be "rather close," the vapor and humidity averaged 7.6, and the carbonic respiratory impurity was 4.132 per 10,000.

3. When the smell begins to be decidedly disagreeable, and the air is called "close," the vapor and humidity averaged 4.9, and the carbonic impurity was from 6.5 to 10.

4. When the organic matter is decidedly offensive and oppressive the air is called "very close," and the carbonic impurity is about 12. Above this the sense of smell is no longer capable of perceiving marked differences.[1]

His conclusion from these results is that to insure the absence of the odor of organic matter in an inhabited apartment, or what he terms "good ventilation," the carbonic impurity due to respiration should not exceed 2 parts in 10,000, and this is the standard accepted by Dr. Parkes and by most recent English writers on this subject.

While this relation between the amount of carbonic acid due to respiration, and the amount of organic matter contained in the air of an inhabited room, and between the latter and the odor produced will be found to exist as a general rule, it varies greatly under certain circumstances.

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[1] Proc. Roy. Soc., London, 1875, p. 187; *ibid.*, Vol. XXV., 1876–7, p. 116.

The smell of organic matter may not be perceptible when the carbonic impurity due to respiration is as high as 5 parts in 10,000, and it may be very decided when the carbonic impurity does not exceed 3 per 10,000. It depends in part on the temperature and the amount of moisture present—in part on the amount of diffusion going on—for the organic matters do not diffuse as readily as the CO_2. Absence of odor does not prove the absence of dangerous particulate impurities in the air, for, although typhus, smallpox and yellow fever cases produce distinct odors, yet there are many of the specific diseases which give no warning of this kind. There does not seem to be any relation between the number of micro-organisms and the proportion of carbonic acid in the air.

The number of observations reported by thoroughly competent and reliable observers as to the relations between respiratory carbonic impurity, organic matter, humidity and temperature are at present much too few to permit of drawing any conclusions of much practical value as regards ventilation, and it is very desirable that further investigations should be made on this point.

It must also be borne in mind that in adopting any standard of purity of the air as expressed by the proportion of carbonic acid found to be present, it is assumed that the amount of CO_2 found in excess of that which exists in the external air is entirely due to respiration, and on the other hand that all the excess of CO_2, due to respiration, is present in a form to be determined by the chemical test. If, for example, one or more lights are burning in the room, we shall find an excess of carbonic acid in the air of that room which has no relation to the organic impurities present. On the other hand, if ammonia be present in the air, as in stables near the floor, it combines with a part of the carbonic acid, and, although the resulting ammonium carbonate is decomposed by the baryta solution in making the chemical test, yet the ammonia then set free in the solution requires a certain amount of the standard oxalic acid solution to neutralize it, and hence the proportion of carbonic acid present appears to be smaller than it really is.

Having fixed upon a standard of permissible carbonic impurity due to respiration, it is easy to calculate the amount of air required to dilute the air expired by an individual for a given time, so that the CO_2 contained in the mixture shall not exceed this standard. The amount of carbonic acid, over and above that inspired, which is exhaled by a person during an hour, varies with his weight, and the state of activity of the different organs of his body. Men exhale more than women, adults more than children, those who are awake more than those

who are asleep. According to Landois and Stirling,* males from the eighth year onward to old age, give off about one-third more CO_2 than females. In old age the amount of CO_2 exhaled diminishes. Thus, in 24 hours the number of grammes of CO_2 excreted is, at the age of 15, 766 ; at the age of 24, 1,074 ; at the age of 50, 889 ; and at 70, 810.

For an adult male, Pettenkofer found that for each pound weight of the body there was excreted, in repose, 0.00424 ; in general exercise, 0.00591 ; and in hard work 0.01227 cubic feet of carbonic acid per hour. Children excrete nearly twice as much CO_2 per pound of body weight. During sleep the amount of CO_2 given off is diminished by nearly one-fourth. In a person affected with fever the amount is markedly increased. A fair average of the amount of CO_2 excreted per hour is, for adult males, from 0.6 to 0.7 cubic foot per hour, and for females, 0.4 to 0.5 cubic foot per hour. Parkes adopts 0.6 cubic foot per hour as the average for a mixed assemblage, and this seems to be a fair estimate.

If now we divide the amount of carbonic acid exhaled in an hour by the limit of respiratory carbonic impurity for good ventilation, we shall have $\frac{0.6}{0.0002} = 3{,}000$, which is the number of cubic feet of air per hour required per person, and this is the standard which is now most commonly accepted by English sanitarians. In this calculation it will be seen that the proportion of carbonic acid in the air as it is delivered into the room is not considered. If this be taken into the account, Seidel's formula is a convenient one, and is as follows :

$$y = 2.30258\, m.\, log.\, \frac{r - q}{a - q}$$

m = volume of air in the room or enclosed space.

p = initial proportion of CO_2 per 1000.

q = proportion of CO_2 per 1,000 in the fresh air introduced.

a = proportion of CO_2 per 1,000 not to be exceeded in a given time.

y = the volume of fresh air to be brought in so that the proportion of CO_2 in the mixture shall not exceed a.

If the time be five hours, the cubic space 20 meters, the CO_2 in the initial and fresh air be 0.4 per 1,000 and the limit of CO_2 be 0.7 per 1,000, then y = 100 cubic meters, or 3,533 cubic feet. In this calculation the amount of expired CO_2 is taken as 20 litres (0.706 cubic feet per hour).

In the eighth edition of Parkes' Hygiene, p. 186, the amount of CO_2 evolved during repose, is given as follows :

* Text Book of Human Physiology. Philadelphia, 1889, p. 233.

"Adult males (say 160 pounds weight)..........0.72 of a cubic foot.
" females (" 120 " ")...........0.6 " "
Children (" 80 " ")..........0.4 " "
Average of a mixed community.....................0.6 " "

Under these conditions the amount of fresh air to be supplied in health during repose, ought to be:

"For adult males..........3,600 cubic feet per head per hour, 102 c.m.
" " females.......3,000 " " " 85 "
" Children.............2,000 " " " 57 "
" a mixed community, 3 000 " " " 85 "

The amount for adult males, as above given, is just over 100 cubic meters, or, if we state it at 3,600 cubic feet, it is just 1 cubic foot per second."

The above figures with regard to quantity of air required for ventilation are in strong contrast to those given in some engineering manuals, and especially those given by Box, which appear to be those of half a century ago. His figures are contained in the following table, from which he concludes that in a room very thinly occupied, 250 cubic feet of air per head per hour is sufficient, and that for crowded assembly rooms, 500 cubic feet per hour is the proper allowance.

Box's Table of Cubic Feet of Air Required for the Different Purposes of Ventilation.

Character of Occupants.	For Respiration.	For Vapor.	For Exhalations	For Heat.	For Lights.
Room with one clean and healthy occupant	22	237	250	220	60
Room with one healthy, but not clean occupant	22	237	350	220	60
Room with one sick man	22	237	1,000	220	60
Crowded room, healthy and cleanly persons	22	237	250	500	60
Hospitals (ordinary)	22	237	2,000	220	60
Hospitals (fever)	22	237	4,000	220	60

It should be observed that the same air serves, simultaneously or consecutively, for all the five purposes assigned.[1]

Taking the allowance of 250 cubic feet per hour, and the amount of carbonic acid exhaled by one person at 0.6 cubic foot per hour, we should find that at the end of the second hour in an ordinary sized room the proportion of carbonic acid in the air of the room would

[1] T. Box, A Practical Treatise on Heat. 7th Ed., 1891, p. 245.

have risen from 4 parts in 10,000, to 24 parts in 10,000, while in the crowded assembly room, with 500 cubic feet allowance per head, at the end of 15 minutes the proportion of carbonic acid would become 12 parts per 1,000. In either case, an offensive musty odor would be produced. There are several sources of error in the calculations of Tredgold and Péclet which are adopted by Box in the above table. In the first place, they assume that the used and contaminated air does not mix with and defile the air in the room, but passes off to a separate place. If each person inhaled air from one reservoir, and expired it into a totally different one, the table would have some value, but this is only the case when a man is working in the armor of a submarine diver, or something of that kind.

The second error involved is one of observation, in the supposition that all the air entering a given room came through the ventilating flue. For example, Péclet states that in a public school of 180 children, of seven or eight years, only a slight odor was perceptible when 212 cubic feet of air per head per hour was supplied, and that in a prison cell with the same supply there was a sensible odor which disappeared entirely when 350 cubic feet were supplied.

These are almost impossible figures, and it is nearly certain that a very large amount of ventilation must have been going on in these rooms through diffusion and leakage of which Péclet's measurements in the flue give no trace.*

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* In this connection the following account of an experiment made by Mr. Putnam, to test the amount of air which passes through the pores and accidental fissures of an ordinary living room, will be found of interest. The room was about 5 meters square and 3 6 meters high, having five windows, two doors and a fireplace, with plastered walls and ceiling and a soft pine floor.

"A flue 10 meters long, from a basement furnace, furnished the rooms with hot air. The windows and doors were first made as tight as possible with rubber moldings. The fireplace was then closed by drawing the damper and pasting paper over the cracks. The brick back and jambs were oiled to render them impervious. All the woodwork was thoroughly oiled and shellacked. A good fire was lighted in the furnace, and the register opened into the room, all doors and windows being closed and locked, and the keyholes stopped up. The hot air entered almost as rapidly with the doors closed as when they stood open, and it continued to enter at the rate of 2.5 cubic meters per minute without diminution as long as the experiment was continued. The thermometer stood at 2° C. outside. The entering hot air ranged from 40° to 55° C. The day was March 3, 1880. Other experiments gave the same results. The pressure of the hot air from the register was sufficient only to raise a single piece of cardboard from the register. A

The third error—which, however, is common to many estimates by physicians as well as by engineers, is the supposition that the exhalations from a sick person are from 4 to 12 times as great as from a person in health. This error was due to the fact that the cause of the infection of hospital wards was not understood, and it was supposed that the contagious matters existed in the form of gas or vapor instead of being particulate, as we now know that many of them are.

General Morin's estimates, which are frequently quoted, but which Box erroneously criticises as being in many cases excessive, are shown by the following table:

Places Ventilated.	Cubic Feet of Air per Head per Hour.		
	Max.	Min	Mean.
Hospitals, ordinary maladies	....	....	2,470
" wounded, etc	....	....	3,530
" in times of epidemic	....	....	5,300
Theaters	1,760	1,410	1,585
Assembly rooms, prolonged sittings	....	....	2,120
Prisons	....	....	1,760
Workshops, ordinary	....	....	2,120
" insalubrious	....	....	3,530
Barracks, during the day	....	....	1,060
" " " night	....	....	1,760
Schools, infant	706	530	618
" adult	1,410	1,060	1,235
Stables	7,060	6,350	6,700

portion of the air must have passed through the pores of the materials, and the rest through cracks and fissures which escaped detection. On the 5th of March a coat of oil paint was applied to the walls and ceilings. This diminished the escape of air only about 5 per cent. On the 19th of March four coats of oil paint had been put on the walls and ceilings, and three coats on the floor, to render them absolutely impervious to air. The escape of air was diminished only about 10 per cent. On the 25th of March all the window sashes were carefully examined, and all visible cracks at the joints, at the pulleys, cord fastenings, etc., carefully calked and puttied, and the entire room examined, and putty used freely wherever even a suspicion of crack could be found. The result of all this was a diminution at the utmost of but 20 per cent. in the escape of the air, or, in other words, in the entrance of air through the register. Each experiment was continued during more than an hour. The air entered as freely at the end as at the beginning of the hour, when a volume of air more than equal to the entire capacity of the room had entered it through the register, with no visible outlet." J. Pickering Putnam. *The Open Fireplace in all Ages*, Boston, 1881, p. 137.

The point of view from which some heating engineers consider this question of air supply is, as expressed by one of them, that "the whole matter, then, resolves itself into opinions as to individual personal comfort, and to observations upon healthfulness of some of the very few rooms and places where, for a period of time more or less extended, a definite ventilation has been maintained." He then goes on to say that 30 cubic feet of air per person per minute is sufficient; that "anything may be called tolerable that is tolerated; anything may be esteemed endurable that is endured. Churches, halls, schools, theaters, state-houses, court-rooms, etc., are rendered tolerable when judicious care is taken in changing the air after a session, and in having fresh air in the audience rooms at the commencement of the same. They are endurable. Not only can little illness or actual disease be traced to them as places of origin, but, on the whole, the audiences accustomed or habituated to the closeness of the air which accompanies any lengthened session, cease to notice what would be excessively disagreeable to the newcomer entering the confined room. People do not willingly find fault when there is apparently no remedy. Perhaps the most striking example of this salutary effect of occasional change of air, as a substitute of ventilation by constant supply, is to be found in our American railroad cars, where, in cold weather, the least amount of regular supply is furnished to the largest number of persons temporarily crowded into the smallest space. To the outsider the heat becomes intolerable; to the insider it is more endurable than any draught of fresh, cold air. The unhealthful condition of the car during six months of the year cannot be questioned; and yet no serious illness that can be attributed to the want of ventilation is found among the tens of thousands of passengers; and it is well known that the conductors, brakemen and others connected with the trains, who live in and out of the cars from day to day, are healthy beyond the healthfulness of most other men."

While there is a certain amount of truth in these statements, the whole impression conveyed by them to the average reader is certainly incorrect. Thirty cubic feet of air per minute, in rooms continuously occupied, will not secure good ventilation; nor is an architect or engineer justifiable in preparing plans upon the basis of such an amount of supply.

Under such circumstances the air will become markedly foul, and will exercise a very deleterious influence upon the health of the occupants, who will be especially liable to consumption and allied diseases if they continue to remain in it for a length of time, and who will suffer

from headache, loss of appetite, want of energy, etc., from even a comparatively short exposure to such a vitiated atmosphere as this insufficient supply will produce.

Every one who has had any practical experience in investigating the condition as to ventilation of assembly halls, hospitals, schools, etc., knows that personal opinions as to the condition of the air at a given time differ widely. One statesman will declare the air of his legislative chamber to be foul and pernicious at the very time when several others will say that it seems pure and satisfactory, and the advocate of some special method of heating and ventilating will invariably find the results produced by that method to be better than most other observers will admit them to be.

Attempts to lower the standard of air supply which has been established by the experiments and observations of physiologists, sanitarians, and vital statisticians, on the plea of demanding positive evidence as to the actual results which foul air produces, or that air which is foul to a certain extent does not, in many instances, produce any perceptible results, must be considered as unwise.

Precisely the same argument will apply to almost all measures which are recommended by sanitarians. In how many houses, for example, is gas from the sewers or from foul soil pipes escaping through pan closets, etc., without producing observed ill effects? And yet is that to be taken as a sufficient reason for abandoning efforts to secure ventilated soil pipes and properly arranged traps? The above argument is one that will be eagerly seized upon by those who have paid no attention to provisions for heating and ventilation for schools, as an excuse for their ignorance, negligence, or parismony, and will be perverted to uses of which the author probably did not dream in writing it.

The conclusion "that for audience halls occupied for sessions not exceeding two or three hours' duration, Dr. Reid's value of 10 cubic feet of air per minute per person * * * is all that should be arranged for when planning such halls; all that can be judiciously urged in the accomplishment of ventilation, in view of the cost of fuel and apparatus; quite sufficient to meet the physiological issue, and so large that it ought to be accepted from the medical point of view," is one that we must most positively deny. The amount of supply for such halls should in no case be less than 30 cubic feet of air per minute through the regular flues of supply, and in legislative buildings the apparatus should be such that at least 45 cubic feet of air per person per minute can be furnished, with a possibility of increasing it to 60

feet per minute when desired. In dealing with such matters as air and water supply, engineers should endeavor to secure maximum and not minimum quantities.

No architect or engineer would advise making plans to correspond with the requirement of 10 cubic feet per minute per person, if the question of expense of construction and maintenance did not come in; and the difference between the opposing views is in the main that one considers the question of cost as more important than others are disposed to do. So far as construction is concerned, the difference in cost between providing for an air supply of 10 and one of 60 cubic feet per minute will not often be so great as to be a serious objection, *provided the plans be made before the construction of the building is commenced.*

It is when we have to provide heating and ventilating arrangements for existing buildings which have been planned in utter ignorance of the requirements of heating and ventilation—and this is the case with at least one-half of our largest and most costly buildings, that we have to diminish the supply of fresh air to the smallest permissible amount in order to be allowed to introduce any at all. The ventilation of such buildings cannot be made satisfactory; it is only "endurable," and a ventilation which is only just "endurable" is discreditable to the architect of the building in which it occurs, provided that his advice has been followed on this point.

Some of the differences in air supply required will be referred to in the chapters on the ventilation of different classes of buildings, of mines, etc. In planning new buildings of a permanent character the architect should not rely on leakage through crevices or on bad construction of the building as a source of air supply. It should be assumed that the walls will be rendered more or less impermeable by paper, paint, etc., and that all the fresh air is to enter through the ducts provided for that purpose. Under these circumstances the flues, registers, heating apparatus, fans, etc., should be adjusted to the following scale of air supply:

	Cubic Feet of Air per Hour.
Hospitals	3,600 per bed.
Legislative assembly halls	3,600 per seat.
Barracks, bedrooms, and workshops	3,000 per person.
Schools and churches	2,400 per person.
Theaters and ordinary halls of audience	2,000 per seat.
Office rooms	1,800 per person.
Water closets and bath rooms	2,400 each.
Dining rooms	1,800 per person.

If this be done it will be comparatively easy to adjust the appliances to a less amount of supply if the occupant be unwilling to pay for the heating and moving of the proper amount, whereas if they are planned for the "tolerable" or "endurable" minimum supply, it will be impossible for them to meet the larger demands which the educated and thinking portion of the community are beginning to make, and which will steadily increase.

If it is a question of ventilating old buildings, where the difficulties are great and minimum amounts only can be provided, furnishing what has been called the air supply of endurance, the above figures may be reduced one-half, but it should be clearly understood that if this be done the results will not be altogether satisfactory, and some odor will be perceived, although no demonstrable injury to health may be produced. Of course, under circumstances which permit the obtaining of larger amounts than those above specified without materially increasing the cost it should be done.

In the open air, with the temperature at 60° F., and when there is no perceptible wind, about 32,400 cubic feet of air per hour will flow over or come in contact with the person of a man supposing his body to present an area of about 9 square feet, and the displacement of air to be at the rate of 1 foot per second. In comparison with this, the allowance of 3,600 feet per hour certainly seems insignificant. It should be remembered, however, that this is the cold-weather allowance, when the incoming air must be warmed, and that in summer the amount should be increased as much as possible, since to do so does not produce increased cost.

For about six months in the year the air may be allowed to sweep freely through inhabited rooms, and the architect may do much to secure facilities for its doing so more commonly than is usually the case. We shall allude to this again in speaking of methods of distribution, and the subject of amount of air supply will also receive further consideration when we come to speak of assembly halls.

The amount of air required for animals has not received much investigation.

F. Smith, in his Manual of Veterinary Hygiene (London, 1887, p. 67), states that a horse exhales about 6.5 cubic feet of CO_2 per hour, and adopting two parts of CO_2 per 10,000 of air as the limit of permissible respiratory impurity, he concludes that in stables 32,500 cubic feet of air should be supplied for each horse per hour.

This is a much larger quantity than that indicated by other writers. Märker estimates that from 1 to 1.5 cubic feet of air per

hour for each pound in weight of the animal is sufficient, but this is certainly much too small an allowance.

In Dr. Carl Dammann's work, Die Gesundheitspflege landwirtschaftlicher Haussäugetiere, 2d edition, Berlin, 1892, p. 677, he estimates that a cow or a horse weighing 1,000 pounds should have 50 cubic meters of air per hour for ventilation.

He uses the formula $y = \frac{k}{p-q}$, y being the amount of air in cubic meters required per hour, k the amount of carbonic acid exhaled by the animal per hour, p the limit of impurity of carbonic acid contents of the air in the stable, and q the carbonic acid contents of the outer and incoming air. For smaller animals he estimates that the supply should be 60 cubic meters per hour per 1,000 pounds of animal.

On page 681 he alludes to the effect of good ventilation in increasing the quantity of milk given by cows; for example, in a cow stable at Frankfort-on-the-Main were 80 Swiss cows; for the years 1877 to 1879, inclusive, the average production per head was 3,700 litres of milk. Good ventilation was then introduced, and the figures per head of milk became:

In the year 1880	4,050 litres.
" " " 1881	4,152 "
" " " 1882	4,355 "

This, however, would require confirmation, and the increase in quantity of milk should, moreover, be compared with the extra expense for warming and for an increased quantity of food, which was no doubt incurred in connection with the extra production.

Small animals require more air in proportion to their weight than large ones, and the so-called wild animals more than those which have been domesticated. Monkeys require a comparatively liberal allowance of fresh air to keep them in good health.

Thus far, in speaking of the quantity of air required, we have been considering only the need for diluting and removing the products of animal exhalation, and, for ordinary living rooms, the amount that is sufficient for this is sufficient for the other purposes for which it is required in human habitations—*i. e.*, to support the combustion of fires and lights, to remove moisture, etc. If the number of lights be large in proportion to the number of persons, it may be desirable to provide a special supply of air to dilute the products of their combustion, and more especially to prevent an undue rise of temperature. A cubic foot of ordinary illuminating gas when burned produces about 2 cubic feet of carbonic acid, and a common gas burner will burn between 2 and 3 cubic feet of gas per hour.

The carbonic acid thus produced is not in itself of much sanitary importance under ordinary circumstances, and in the United States it is rare that other substances, such as sulphur dioxide, are formed in sufficient quantity to be annoying. Wolpert estimates that 1,800 cubic feet of air should be supplied tor every cubic foot of gas consumed—and this estimate is approved in the last edition of Parkes' Hygiene, which would imply that over 4,000 cubic feet of air per hour should be furnished for every gas burner. One-fourth of this amount is probably ample. In assembly halls, theaters, etc., the electric light is now taking the place of gas, and of course requires no provision for air supply.

In exceptional cases the amount of air supply is to be calculated with reference to its being a medium for the conveyance of heat. If, for example, a room is to be warmed by heated air, the so-called method of indirect radiation, a certain amount of air must be supplied, even if the room is unoccupied by human beings. The amount of air required for this purpose depends on the temperatures required—amount of exposed wall and window surface, amount of leakage around doors and windows, etc.—but the usual rough estimate is that it should be per hour about one and a-half times the number of cubic feet contained in the room to be thus warmed. Unless this amount of change be secured when the external temperature is below the freezing point, either the room will not be kept comfortably warm or the incoming air must be introduced at a much higher temperature than is desirable. This rule will not apply to very lofty rooms where the heated air will accumulate near the ceiling, leaving the floor cold.

The higher the external temperature the more air is required to secure comfort, up to the point when the air becomes so warm and moist that it no longer serves to remove the animal heat. In a hot, moist summer day, sufficient ventilation cannot be secured even out of doors, especially if a crowd be collected.

Some heating engineers are in the habit of making all their calculations as to amount of air supply with reference to the frequency with which the air in the room is to be changed—and will say that they propose to change all the air in the room three, or four, or six times per hour, instead of calculating the number of cubic feet required for the number of persons in the room.

This is not a satisfactory mode of calculating or stating the requirements, because of the great variations in cubic space per person in different classes of rooms.

Cubic space is an important factor in ventilation in some cases, while in others it is of very secondary importance.

The most valuable paper on this subject is the "Report of the committee appointed to consider the cubic space of Metropolitan Workhouses," published in folio as a parliamentary blue-book in 1867.

This contains papers by Drs. Acland, Angus Smith, Markham, Parkes, Donkin and others, in which the matter is fully discussed.

Assuming that the harmful matters in the air of an occupied room are constantly and equably produced, and are uniformly diffused—and may be represented by the carbonic acid present, Professor Donkin gives the following formula:

$$x = p + \frac{P}{A} - \frac{P}{A}\ 2.718 - \frac{At}{c} \quad \text{in which}$$

x is the number of units of CO_2 per cubic foot in the air of the room at the end of t hours.

P is the number of units of CO_2 produced in the room per hour when it is occupied.

A is the number of cubic feet of fresh air per hour introduced (and also the volume of air escaping during the same time).

p is the number of units of CO_2 per cubic foot in the fresh air introduced.

c is the number of cubic feet in the room.

The numercial value of the last term in the equation diminishes rapidly as t increases and becomes insensible. After a number of hours depending on the ratio of A to C, the final value becomes:

$$x = p + \frac{P}{A} \text{ whence } A = \frac{P}{x - p}$$

For example: suppose a man produces 6 units of carbonic acid per hour, and fresh air contains .004 such units per cubic foot; if it is required to maintain a room (of whatever size), constantly occupied by one man, in such a condition that the units of carbonic acid in a foot shall never exceed .006, then

$$A = \frac{6}{.006 - .004} = 3{,}000,$$

that is 3,000 cubic feet of fresh air must be supplied per hour.

In this case, at the end of t hours after the room begins to be occupied, the number of units of carbonic acid per cubic foot is

$$.006 - .002 \times e - \frac{3.000\, t}{c}$$

where c is the number of cubic feet in the room.

Thus, suppose the room contains 1,000 cubic feet, then the units of carbonic acid per cubic foot are,

At first	.004
After 1 hour	.005900
" 2 hours	.005995
" 3 "	.0059997

so that after two hours the room would have *sensibly* reached the final condition of .006 units per cubic foot. If the room contained only 100 cubic feet, the approximation to the final state would be much more rapid. His conclusion is that, uniform diffusion being supposed, the same supply of air will, after a short time, equally ventilate any space. The assumption of uniform diffusion is rarely correct in any given case, because the diffusion of gases does not go on so rapidly as to overcome the effects of currents of air produced either by mechanical means or by different temperatures, and such currents almost always exist in a room occupied by men, so that marked differences may thus be produced in the composition of the air in different parts. Usually the upper strata will contain a little more carbonic acid and watery vapor. The formula for the amount of fresh air necessary to reduce a vitiated atmosphere to a required standard of purity is given by De Chaumont as follows:

Let R be the ratio of carbonic acid in incoming air.
" r' " " " " vitiated air.
" c be the capacity of original air space in cubic feet.
" r be the desired ratio of purity to which r' is to be reduced.
" d be the delivery of fresh air in cubic feet.
" v be the total volume of air, $c + d$.

$$\text{Then: } \frac{r' - R}{r - R} \times c = v, \text{ and } v - c = d.$$

It will be at once seen by the above formula that when $r = R$, that is, when it is wished to restore c to the purity of the external air, v and d become *infinity*, so that complete purification of c is, under these circumstances, theoretically impossible.

To determine the number of men, n, a cubic space, c, will accommodate, we have the following, r and R being the ratio per cubic foot, e the CO_2 expired by one man in an hour (= .6 cubic feet), and h the number of hours:

$$\frac{(r - R)\, v}{e\, h} = n$$

To determine the delivery of air required to maintain an unoccupied space at a given ratio of purity, r, we have:

$$\frac{n\, e\, h}{R - r} = v, \text{ and } v - c = d.$$

In computing cubic space for purposes of ventilation, heights of rooms above 12 feet should be disregarded. With this limitation the minimum amount of cubic space which should be given may be stated as follows:

In a common lodging or tenement house	300
In a school-room	250
In a barrack dormitory for soldiers or police	600
In an ordinary hospital ward	1,000
In a fever or surgical ward	1,400

Taking the standard of 3,000 cubic feet of air per hour per head, the following table by Parkes shows the amount of air necessary to dilute to this standard :

Amount of cubic space (breathing space) for one man, in cubic feet.	Ratio per 1,000 of carbonic acid from respiration at the end of one hour if there has been no change of air.	Amount of air necessary to dilute to standard of .2, or including the initial carbonic acid, of .6 per 1,000 volumes during the first hour	Amount necessary to dilute to the given standard every hour after the first.
100	6.00	2,900	3,000
200	3.00	2,800	3,000
300	2.00	2,700	3,000
400	1.50	2,600	3,000
500	1.20	2,500	3,000
600	1.00	2,400	3,000
700	0.85	2,300	3,000
800	0.75	2,200	3,000
900	0.66	2,100	3,000
1,000	0.60	2,000	3,000

The above table refers to rooms occupied for a number of hours consecutively.

In any given case the amount of air required for each room will depend on the dimensions of the room, the difference between the external and internal temperatures, the number of persons occupying it, their character or occupation, and the length of time they are to remain in it.

In rooms occupied for several hours, such as bedrooms, dormitories, hospital wards, etc., cubic space is important mainly with reference to the possibility of moving the required amount of air through the room without giving rise to unpleasant currents or draughts, and secondarily, in reference to the amount of wall space, cracks, etc., available for the diffusion or leakage of air. In attempts to regulate the air supply of certain classes of people by legislation or regulation—as is done for common lodging and tenement houses, and in England for

soldiers and school children—it is always the cubic space and not the amount of air supply that is prescribed, owing probably to the fact that it is much easier to determine the former than the latter. With air warmed to an agreeable temperature, and many inlets and outlets of large aggregate area to ensure proper distribution, and with sufficient mechanical power to ensure the requisite movement, it would be possible to furnish the required amount of air without perceptible draughts when the cubic space was small. At temperatures of from 65° to 75° F., air moving at the rate of 1½ feet per second will not be felt as a current. If, therefore, in a room 10 feet square and high, the floor and ceilings be made practically gratings, and air at 70° F. be drawn through so as to secure an uniform upward or downward current throughout the room having a velocity of 3 inches per second, we should have 25 cubic feet of air per second passing through without perceptible current—a quantity sufficient for the needs of 25 persons—who, if packed into such a room, would have only 40 cubic feet of air space each. This is of course purely theoretical—and, under ordinary circumstances, in rooms of the usual dimensions, it is not possible to change the air more than four times per hour, and if each person is to have 3,000 cubic feet of air per hour, he will therefore need 750 cubic feet of air space.

The British army regulations allow 600 cubic feet of air space per head for soldiers in barracks, in lodging houses from 240 to 300 cubic feet per head are required, in the London schools from 130 to 300 cubic feet must be furnished.

In this connection it should be noted that floor space must be considered as well as cubic space.

In hospitals each bed should have 100 square feet of floor space at least. The space required in stables was fixed by the Barrack and Hospital Improvement Commission, at 100 square feet of floor space and about 1,600 cubic feet of air space for each horse, but this amount is not actually furnished. In cow stables each animal should have at least 900 cubic feet of air space in order to prevent disease, and 1,200 cubic feet would be a much wiser allowance.

In the report on cubic space above referred to, Dr. Angus Smith remarks that the advantage of large spaces is that if there is imperfect ventilation, the results are less rapidly perceived, that small spaces require constant ventilation, but this can be made satisfactory if the air is of a proper temperature, and that larger spaces are needed for high than for low temperatures, the aim being to change the air as often as is compatible with warmth.

CHAPTER VIII.

ON THE FORCES CONCERNED IN VENTILATION.

VENTILATION is produced by the movement of air, and such movement is due to some force, either derived from what may be called the natural conditions of the locality, or specially developed and applied for the purpose of producing currents.

In ordinary dwellings, and for almost all buildings where but few persons are gathered in each room, it is unnecessary to provide special apparatus for forcing or increasing the movement of the air. During warm weather, open windows and doors afford, in most cases, sufficient change of air, and in cold weather the expansion of the air by the action of the heating apparatus and the increase of temperature due to the bodily warmth of the tenants, to lights, etc., furnish sufficient motive power if the flues and registers are of proper size and rightly placed. To this may be added the effects of diffusion through the walls when these are not painted, papered or otherwise made impervious, and the leakage through cracks and crevices, which is an important factor in ordinary dwellings.

But in this country and climate there are a certain number of days in the spring and fall when it is too warm to permit of the use of heating apparatus, and when there is no wind. In halls of assembly of all kinds, and especially in theaters, in hospitals, in certain manufactories where noxious or offensive gases or dusts are produced, and in mines, tunnels, etc., it is often very desirable, and sometimes absolutely necessary to provide power sufficient for the movement of the requisite quantity of air, which power shall be independent of the heating apparatus. Ventilation thus produced or assisted is by some writers termed artificial, as opposed to what they call natural ventilation, but a better term for it is forced ventilation.

The power necessary to effect this forced ventilation may be derived from the expansion of air by heat specially applied for that purpose in the outlet flue or chimney, or from fans or blowers driven by machinery, or from jets of compressed air, or of steam, or from a falling stream of water. It is also theoretically possible to produce the

required movement of air by cold as well as by heat; all that is essential being that there shall be a difference in temperature between the space to be ventilated and the outer air, and sufficient channels of communication between the two.

Wind is a powerful ventilating agent, either acting by perflation through open windows and doors, or by pressure against porous walls, or by modifying the flow of air through inlet and outlet flues. It is the best of all means when artificial heat is not required, but it is irregular in its action, and cannot be depended upon as a motive power. With this may be mentioned the force produced by movement of the enclosed space through the atmosphere, as in the case of railroad cars or steamships. We shall consider this kind of motor power hereafter in speaking of cowls.

In Chapter II. we have spoken of some of the physical properties of the air, and have given the formulæ for its expansion by increase of temperature, and the consequent effects in the form of upward currents. We have now to consider these in their practical application to chimneys, and especially to chimneys or large upcast flues intended, mainly or exclusively, to produce ventilation by the action of a column of air which is warmer than the surrounding atmosphere, and which are commonly termed aspirating flues or chimneys.

To determine the volume of air passing through a chimney in a given time, we wish to know the area of its cross-section at some given point, and the velocity of the current at this point. If the volume in cubic feet discharged per second be designated by Q, the area in square feet by A, and the velocity in feet per second by V, then $Q = A \times V$. If we wish to determine the area of the cross-section which a flue or chimney should have, we usually first determine the quantity of air which it is to transmit per second, and then, assuming such figure for the velocity as may seem most economical and practical under the circumstances, solve the problem by the formula $A = \frac{Q}{V}$.

In deciding as to the figure for the velocity to be used in the above formula in determining the capacity of a chimney already built, or the area to be given to a chimney flue to enable it to transmit a given quantity of air, the following considerations should be kept in mind:

If the chimney is already built, the velocity may be measured by means of an anemometer, or by observing the time required for a puff of powder smoke generated at the bottom to escape at the top; but for openings, flues and chimneys as yet unconstructed, this velocity must be calculated. The calculation cannot be made accurate, as we shall

see, but very useful results may be obtained from it. The theoretical velocity, when friction is not taken into account, is calculated in several ways, but that which is now most commonly used depends upon what is known as the law of Montgolfier, or the law of spouting fluids. This law is that fluids pass through an opening in a partition with that velocity which a body would attain in falling through a height equal to the difference in depth of the fluid on the two sides of the partition, or, what is the same thing, the difference in pressure on the two sides. The velocity in feet per second of falling bodies is about eight times the square root of the height from which they have fallen expressed in feet, and the formula for determining this is $v = c\sqrt{2gh}$.

In this equation v is the velocity to be found, stated in feet per second; g is the velocity which a body falling freely from a state of rest has at the end of one second—which is 32.2 feet per second; h is the distance fallen through by the body; and c is a constant, determined by experiment, which expresses the proportion of the actual to the theoretical velocity.

The height h, fallen through by the cold air, is to be determined by the law of the expansion of gases, which, for our purpose, may with sufficient accuracy be taken to be $\frac{1}{491}$ of its volume for each degree F. of increase of temperature. In the case of a chimney, the force which drives the warm air up the flue is the force of gravity, or the excess of gravity or weight of a column of cold air over a precisely similar column of warm or expanded air, which is the difference in pressure above referred to.

This difference in pressure is found by multiplying the height from the opening at which the air enters the flue to that from which it escapes by the difference between temperature outside and inside, and again multiplying this product by $\frac{1}{491}$. The formula for the theoretical velocity then becomes

$$v = 8\sqrt{\frac{(t-t') \times h}{491}}$$

in which t is the temperature in the chimney, t' the temperature of the external air, and h the height of the chimney.

Suppose, for example, that the temperature in the chimney is 100 degrees, that of the external air 40 degrees, and that the chimney is 50 feet high, we shall have

$$v = 8\sqrt{\frac{60 \times 50}{491}} = 8\sqrt{6.11} = 20$$

nearly, or the theoretical velocity would be 20 feet per second.

This theoretical velocity will be diminished by friction, by angles in pipes and flues, and by eddies or counter currents, and on the other hand it may be increased by the aspirating effect of wind passing across the top of the flue.

The general rule is that the real velocity in a chimney flue will be less than the theoretical velocity by from 20 to 50 per cent. It is because of this difference that minute calculations are useless, and that a slightly inaccurate formula is given because of its simplicity, and the ease with which it can be remembered. From what has been said, it will be seen that the velocity of the ascending column of air in a heated chimney depends upon the difference in temperature between the air in the chimney and that outside. The greater this difference up to temperatures of 800° F., the greater the velocity, other things being equal. The velocity also depends on the height of the chimney, the general rule being that the velocity increases with the height. This, however, is neither theoretically nor practically correct, except within certain limits. The formula assumes that we use in our calculations the mean temperature of the shaft. It must be remembered that there is a very considerable loss of heat from the external surface of the chimney itself, and the higher the shaft the greater the amount of this surface and the greater the loss, thus neutralizing to a certain extent the effect of the increase in height.

The problems relating to velocities of currents and areas of flues, more especially in chimneys, are comparatively simple, if the nature of the force which produces draught in a chimney be clearly understood; but the popular mind is by no means clear on this point. Many persons seem to suppose that a chimney has some independent power of its own, and in this sense say that it draws well or draws badly. A mason has been known to contend that the chimney itself must do some of the work, independent of heat, because, in a house which he was then at work on, he found an upward current in the chimney, although the roof had not yet been placed on the building, and it required several trials under different circumstances to convince him that this current was due to the heating by the sun of the south wall in which the chimney was placed.

Of course, if a chimney had any such power as he supposed, we should have a sort of perpetual motion, and, as Mr. Edwards remarks, upon this theory it would only be necessary to build a few gigantic chimneys to work all the mills in a place without the use of coal.

The velocity in a chimney should be sufficient to maintain a steady, uniform flow, without eddies or currents; and, at the top of

the chimney, it should be so great that the usual winds will not interfere with it, which will necessitate a rate of about 10 feet per second. If it be greater than this there will be a waste of fuel, for we have seen that this velocity depends upon the temperature to which the air is heated, and every unit of heat contained in the air escaping at the mouth of the chimney which is in excess of the number of units required to prevent eddies and counter currents, is so much useless expenditure. It is, moreover, quite unnecessary to keep the velocity in the shaft as great as that at the outlet; and it is very poor economy to do it, because the friction increases rapidly with increase of velocity, and requires more force, or, what is the same thing, more fuel, to overcome it. The velocity in the main flue of the chimney of an ordinary dwelling house should be about 5 feet per second; whence it follows that the area of opening at the mouth of the chimney should be about one-half that of the main flue.

The increase of temperature in the chimney which will be required to produce this velocity depends, of course, upon its height, but for a shaft about 40 feet high the increase over that of the external air should be at least 10° F.

Of late years the tendency of architects and builders in this country has been to make their flues too small, which is probably due to the very general use of stoves. In shunning this error care must be taken not to fall into the opposite extreme, for "the expedient of constructing everything a little larger than is necessary in order to have a reserve for contingencies is not always a safe one," at least if due regard be given to economy. If a chimney shaft has a larger area than is necessary, down draughts will be formed in it when a sufficient supply of heated air is not provided for it, while, if this supply be given, more air, and therefore more heat, than is requisite must be furnished. The use of movable valves or dampers at the base of the shaft will prevent the last evil, but will aggravate the first; and the same is true as regards the very common expedient of a valved opening at the base of the shaft to allow air from the boiler room to enter the chimney direct, and therefore diminish the draught. If the valve be placed at the top of the shaft both evils may be corrected within certain limits, and such valves will sometimes be found of great use.

The shape of the flue should be as nearly round or square as the size of the walls and jamb will permit. The circle is the best form, because it gives the greatest area in proportion to the perimeter, or surface-producing friction, and the square is next. If the flue be rectangular in shape, with one diameter of not more than 4 inches, the

friction will be great, and if such a flue be so placed in a wall that one of its long sides is parallel to a surface of the wall which is exposed to cold air, there will be great loss of heat.

If we consider chimney flues as intended only to carry off the products of combustion, without reference to questions of ventilation, the following are the sizes which give the best results: For ordinary dwelling houses the flue for each room, if built of brick in the usual way, should be about 1 foot square, or for common bedrooms 9″x 12″. If the flues be lined with smooth pipes of pottery or cement they may be 9 inches in diameter.

The sizes of chimney flues used in ordinary dwellings vary in different parts of the country. In Boston, New York and Chicago such flues are usually 8″x 8″ or 8″x 12″. In Baltimore the flues are usually 13″x 13″. In New Orleans the common size is 9″x 9″.

This difference depends in part upon variations in size of brick in common use, in part upon the more general use of closed iron stoves in the North, and in part to traditions of masons and builders, of which it would be very difficult to trace the origin. Tredgold's rule for chimneys for steam boilers is as follows: "The area of a chimney in inches for a low-pressure steam engine, when above 10 horse-power, should be 112 times the horse-power of the engine, divided by the square root of the height of the chimney in feet. *Example:* Required the area of a chimney flue for an engine of 40 horse-power, the height of the flue being 70 feet.

"In this case

$$\frac{40 \times 112}{\sqrt{70}} = 533.2$$

square inches. The square root of this is 23 inches, which will be the side of a square chimney. Or, multiply 533 by 1.27 and extract the square root for the diameter of a circular one."

In another place, however, Mr. Tredgold advises that chimneys be built double the size called for by this rule. Mr. Milne substitutes 280 for 112 in the above formula, and thus obtains results between two and three times as great. Milne's rule is as follows: The square root of the height of the chimney in feet multiplied by the square of its internal diameter at the top or narrowest part in feet is equal to twice the horse-power of the proper boiler for the chimney.

By horse-power in this connection is meant the evaporation of a certain amount of water—the usual estimate being that a cubic foot of water at 60 degrees evaporated to steam is equal to one nominal horse-power, which, in round numbers, would require 70,000 thermal units.

The judges at the Centennial defined a horse-power to be equal to the evaporation of 30 pounds of water from a temperature of 212 degrees. As a cubic foot of water weighs a little over 62 pounds, this standard requires less than half the fuel which would be needed for the former—being only about 29,000 thermal units. Taking the older and more usual estimates used by Tredgold, allowing eight pounds of coal per hour per horse-power and 300 cubic feet of air for the combustion of each pound of coal, we find that we shall have for a 40 horse-power boiler about 30 cubic feet of gases per second to dispose of. If we allow a velocity of 5 feet per second in the flue we shall want a flue having an area of 6 square feet, which result is intermediate between those of Tredgold and Milne, and is probably more nearly correct than either.

Another rule is that of Murray—18 square inches for 12 pounds of coal per hour.

Another rough-and-ready rule for chimneys for the ordinary horizontal flue boilers is, that the chimney should be from 60 to 80 feet high, and have an area equal to half the square of the diameter of one of the tubes multiplied by the number of tubes. In such a boiler 15 feet of boiler surface is taken as equal to one horse-power. Still another rule-of-thumb is that the size of the flue should be equal to the area of the tubes.

The following are the formulæ of the Babcock & Wilcox Co., of New York, for chimneys, allowing five pounds of coal per hour per horse-power, and taking friction as equal to a layer of air 2 inches thick over the interior surface:

A = area in square feet.
E = effective area.
H = horse-power.
h = height of chimney in feet.

$$E = \frac{0.3\,H}{\sqrt{h}} = A - 0.6\sqrt{A}$$

$$H = 3.33\,E\sqrt{h}$$

$$h = \left(\frac{0.3\,H}{E}\right)^2$$

For a 27 horse-power boiler E will be:

For a chimney 25 feet high	1.62	square feet
" " 36 " "	1.35	"
" " 49 " "	1.16	"
" " 64 " "	1.01	"

The following table is given by Prof. W. P. Trowbridge in his book, "Heat as a Source of Power:"

TABLE SHOWING HEIGHTS OF CHIMNEYS FOR PRODUCING CERTAIN RATES OF COMBUSTION PER SQUARE FOOT OF AREA OF SECTION OF THE CHIMNEY.

Heights in Feet.	Pounds of Coal Burned Per Hour Per Square Foot of Section of Chimney.	Pounds of Coal Burned Per Hour Per Square Foot of Grate, the Ratio of Grate to Section of Chimney Being 8 to 1.
20	60	7.5
25	68	8.5
30	76	9.5
35	84	10.5
40	93	11.6
45	99	12.4
50	105	13.1
55	111	13.8
60	116	14.5
65	121	15.1
70	126	15.8
75	131	16.4
80	135	16.9
85	139	17.4
90	144	18.0
95	148	18.5
100	152	19.0
105	156	19.5
110	160	20.0

In this connection it may perhaps be well to say a word about smoky chimneys, although in this country we are not troubled with them to anything like the extent that they are in England, judging from the amount of English literature on that subject. This is due to the fact that we do not use open fireplaces nearly so much as they do in England, and that we have a much drier climate. In some of our public buildings where open grates are used there has been trouble from smoke, and a very amusing account is given of the efforts made to cure it in one of the large public buildings in Washington, in which there was a series of rooms freely communicating with each other, and each having an open grate. When the watchman began to build the fires in the morning he found the first one had a magnificent draught, the second one not so good, the third very dubious indeed, and the fourth smoked furiously. Then came the chimney doctor with a patent chimney top, which was placed on flue No. 4, lengthening it about 3 feet. No. 4 now drew well, but No. 3 was no longer dubious, for it smoked like a tar kiln. Of course the same remedy was

applied to No. 3, but then Nos. 1 and 2 became a nuisance. When these also had been duly finished with the patent chimney tops, all the flues were again of the same height, and the process had to be begun *de novo*. The true remedy in such a case is to see that each chimney has its own sufficient supply of air from without, and does not draw against another flue.

A damp flue is another cause of smoky chimneys, since the current of ascending air is rapidly cooled by evaporation. This often adds greatly to the difficulty of keeping a smoke flue situated in an outer wall in good working condition.

The effects of wind on the action of chimneys will be considered hereafter.

With an atmospheric pressure equal to 29.92 inches of mercury, and at the temperature of 52° F. 1 cubic foot of dry air weighs .0776 pounds; that is, 13 cubic feet of air weigh about one pound. The specific heat of air, with constant pressure is 0.2379; that is, one pound of air will be raised 1 degree in temperature by that fraction of a thermal unit, or one thermal unit will raise the temperature of one pound of air 4.2° F. If we assume that one pound of coal as usually burned, produces 8,000 available units of heat, it will heat 8,000 pounds = 104,000 cubic feet of air, 4.2° F., or it will lift this same weight of air 772 feet. In heating air at constant pressure a certain amount of heat disappears in producing expansion of air, and this expansion gives buovancy or ascensional force which may be used to secure ventilation. But in doing this the air passing off carries off heat with it, and that heat is no longer available for warmth—a fresh amount must be supplied to the air which enters to take its place. The more we ventilate an inhabited room in cold weather, the more heat we must supply, and therefore the more fuel we must burn. We may do much to secure complete combustion of our fuel, and to prevent waste of heat, but we can only get 100 per cent. of effect, and by no form of apparatus is it possible to effect the heating of a well ventilated room with the amount of fuel that would heat the same room if the change of air were only sufficient for heating purposes.

We often find inventors claiming that their special appliances will give both ample heat and abundant ventilation with diminished consumption of coal, but there is little use in wasting time over the examination of plans or proposals for contracts in which this claim is made.

To completely burn one pound of coal requires about 295 cubic feet of air, and all the nitrogen, oxygen, carbonic acid, and vapor of

water in this air must be heated, and will therefore absorb and carry off some of the thermal units. Whatever may be the methods of ventilation employed, there is but one mode of getting rid of the products of combustion of fuel that need be mentioned here, and that is by using the force due to the expansion of gases by heat.

The force with which the gases from the burning fuel tend to rise in a chimney may be, under ordinary circumstances, measured by the temperature at which these gases enter the flue. The lower this temperature, the more economical the apparatus, so far as heating is concerned. From an ordinary steam boiler the products of combustion enter the chimney at a temperature of 550° F.

From a good hot-water boiler, properly fired, these products of combustion enter the chimney at about 300° F., the temperature of the water in the boiler being 160° F., while from a so-called air-tight stove, with a large amount of pipe, they may pass into the chimney at 150°, or even so low as 100° F.

These are merely average figures. By special arrangements it is possible to cause the gases from the furnace of a steam boiler to enter the chimney at a much lower temperature, even as low as from a stove; but such arrangements are seldom used, since with coal at present prices it seems cheaper, on the whole, to use the usual forms of apparatus.

Heated air in a bottle having a narrow, open mouth, will not rise, because the colder air around cannot enter to force it out; but if the mouth be divided by a partition a current will soon be established, the cold air flowing down on one side and the warm air streaming up the other. This is commonly illustrated by those advocating the use of a patent ventilator which depends on this principle, by an experiment which always deeply impresses those who see it for the first time, and the exhibition of which has sold many ventilators—and purchasers. This experiment consists in placing a short piece of lighted candle in the bottom of the bottle. The heat of the flame promptly sets up a circulation within the bottle, which continues until enough carbonic acid has been produced to extinguish the light. If, just before the light goes out, a partition be inserted in the neck of the bottle, the effect above mentioned will be produced; the smoke will be seen streaming out on one side, and the light will soon burn again as brightly as ever. For ventilating a bottle, or a place which is under the same conditions as a bottle, this is a very good method; but if you ever put such an arrangement into a house you will find that when cold weather comes it will be carefully closed. On the other hand, warm air

will not rise through a small opening into a room filled with cold air unless this room has some opening by which some of its contained air will escape. Forgetfulness or ignorance of this fact sometimes causes great disappointment to the amateur furnace-setter, who cannot imagine why an apparatus will not heat a room above it in which every aperture has been closed "to keep in the heat." The quickest way to heat a room under such circumstances is to open the window. It will be found useful to remember the bottle and the demoralized furnace-setter when a client complains of a smoky chimney.

Forced ventilation by heat will usually be effected by what is commonly called an aspirating or ventilating chimney, which is a shaft or flue so constructed that the air in it can be heated without necessarily heating the room or rooms from which it is desired to withdraw the air, so that no discomfort need be caused by its use in warm weather. This heat may be applied by means of an open grate placed in the shaft, as is done in the aspirating tower for the House of Commons, and in some mines, or by means of a stove, heating a sheet-metal pipe passing up the chimney, or by gas jets, or hot-water boilers, or by the circulation of hot water or steam in coils of pipes or radiators suitably arranged in the chimney, and known as accelerating coils.

The open grate is a wasteful and troublesome mode of applying heat for this purpose, and should only be employed under very exceptional circumstances.

The use of gas jets would also be very expensive in this country if the amount of air to be moved is large. The necessary fixtures for the gas heating of a flue can, however, often be introduced in old buildings where any other sort of apparatus would be practically out of the question, as they take up very little space, and for the ventilation of a water closet, or similar purposes, this method gives fair results at small cost. But while the use of gas combustion as a means of forcing ventilation is, for economical reasons, not to be recommended if this is to be the sole purpose for which the gas is consumed, it should not be forgotten that the burning of gas for illuminating purposes gives rise to heat which can often be made use of advantageously for purposes of ventilation. This is especially the case in theaters and other large assembly halls which are used at night, in which a very considerable amount of aspirating power may be obtained by suitable connection of tubes and flues with the means of illumination.

The heating of the aspirating chimney by means of a central metal pipe is a method very commonly employed to utilize the waste heat from the flues of steam boilers, etc., and gives very excellent results,

as may be seen by referring to those obtained in the Barnes Hospital, described in a subsequent chapter. In private houses the kitchen chimney is sometimes used in this way as a ventilating shaft for the whole or a part of the house, the pipe from the stove or range being carried up through the center of the chimney flue.

The application of steam heat for the purpose of accelerating the movement of air in ventilating flues is often a very convenient and satisfactory method where this source of power is available; but the amount of heating surface allowed for this purpose by many heating engineers is very insufficient for the purpose, and the coils are often wrongly placed.

Prof. W. P. Trowbridge, of Columbia College, published in 1882, in the *School of Mines Quarterly*, a very excellent paper on the "Determination of heating surface required in ventilating flues," with special reference to the formulæ used in calculating this for coils of steam pipe, and subsequently gave a brief article on the same subject in the *Sanitary Engineer*, which is so clear and concise that it is here quoted:

"The employment of steam pipes at the bases of ventilating flues seems to me to be worthy of more extended application than has heretofore been accorded to this method of promoting activity of circulation of air for the purposes of ventilation. It is only applicable, of course, for buildings heated by steam; but of buildings thus heated, a few only, such as hospitals, asylums, theaters, and other public buildings, are of sufficient magnitude, or are occupied by such numbers as to warrant the use of fans or blowers.

"Ordinary architectural structures must have appliances for ventilation which demand the least possible attention; or, perhaps, no attention whatever, except the opening or closing of registers. And yet it is well known that when under these circumstances spontaneous or natural ventilation is depended on, there are occasions and circumstances when partial or complete stagnation of air is inevitable. In buildings heated by steam the remedy is simple and effective. Steam, or even hot-water pipes properly arranged at the base of any vertical flue will furnish the necessary heat to produce a draught. The simple question involved is the area of heating surface demanded for a given vertical flue, and for a given quantity of air to be discharged per hour.

"In a paper first published in the *School of Mines Quarterly* (the abstract results of which were printed afterward in the *Sanitary Engineer*), I discussed the question and deduced a simple formula for the heating surface. I now venture to refer to that formula, and show how it may be used with the least amount of arithmetical calculations.

"The formula is as follows :

$$S = \frac{W\, T_a}{H\,(T_s - T_a)} \times 1{,}500.$$

"In this formula (S) represents the number of square feet in the exterior surface of the coil or cluster of steam pipes at the base of the flue ; (T_a) is the absolute temperature of the external air—that is, the common or thermometric temperature $+ 459.4°$ (or $t° + 459.4°$).

"(W) represents the weight of air in pounds which is discharged in one second.

"(H) represents the height of the flue, and (T_s) is the absolute temperature of the steam in the coil (*i. e.*, $t_s + 459.4°$).

"The constant 1,500 is derived from certain constants which were employed in deducing the formula, one of which was the force of gravity, another the specific heat of air, another the rate of transfer of heat to air by coils, from Mr. C. B. Richard's experiments, and another the ratio between the theoretical velocity and the actual velocity in the flue, as influenced by friction. For ordinary and the most favorable circumstances the actual velocity in the flue is best if it be established at about 5 feet per second, and it is for this actual velocity that the formula in its simplified form as above is adopted.

"Another formula, well known, and which is needed, is that for the weight of air discharged per second—to-wit :

$$W = A \times D_c \times V.$$

"That is, the weight discharged is found by multiplying the cross-section of the flue (A) by the velocity (V) and the density (D_c) of the air in the flue.

"By the calculations in my original paper, I found that the density in the flue which will result from the proportions given by this formula, will be 0 0719 pounds per cubic foot. Hence the area of flue for a given discharge, W, will be :

$$A = \frac{W}{D_c\, V} = \frac{W}{0.0719 \times 5} = \frac{W}{.3595}$$

or, $A = 3\,W$ approximately.

"That is, the cross-section of the flue in square feet should be three times the weight of air discharged per second.

"An example will show the method of using these formulas for all ordinary cases.

"Suppose the air of a room 30′x40′ and 15 feet from floor to ceiling is to be renewed four times every hour.

"The cubic contents are $30' \times 40' \times 15' = 18{,}000$ cubic feet. At the ordinary temperature and pressure, this air will weigh about $\frac{8}{100}$ of a pound per cubic foot, and the weight of air discharged per hour will be $4 \times 18{,}000 \times .08 = 5{,}760$ pounds, or 1.6 pounds per second.

"The required area or cross-section will be $A = 3. \times 1.6 = 4.8$ square feet. If, now, we suppose the steam in the coil to be low-pressure steam, for instance five pounds above the atmosphere, we shall have for its temperature, F. 228°, and if we assume the exterior temperature of the air to be 60 degrees, we shall have conditions which will apply to spring or autumn weather, and the same arrangements then determined will give better results in winter or cooler weather; with these assumptions we have:

$$S = \frac{1500 \times 1.6\ (60 + 459.4)}{H\ (228^\circ + 459.4 - 60 + 459.4)}$$

or,
$$S = \frac{1500 \times 1.6\ (60 + 459.4)}{H\ (228^\circ - 60^\circ)} = \frac{4.9}{H} \times 1500.$$

"If the flue is 50 feet high, we shall have:

$$S = \frac{1500 \times 4.9}{50} = 30 \times 4.9 = 147 \text{ square feet.}$$

"Hence, the conditions of ventilation assumed will require an aggregate area of ventilating flue of $4\frac{8}{10}$ square feet in cross-section, and 147 square feet of heating surface in the coil or cluster of pipes at the base.

"If more than one flue is employed, which would probably be desirable, in order to have a better distribution of the inflowing air (two flues for instance), then each would have an area of $2\frac{2}{10}$ square feet, and each would be heated at the base by pipes having $73\frac{1}{2}$ square feet of surface.

"It may be thought that this amount of surface is excessive for the degree or ventilation assumed.

"The reply to this objection is, that if any one expects to obtain full and sufficient ventilation without expending an appropriate amount of money, both for fixtures and for fuel, such a one is mistaken.

"It might as well be expected to get water from a well without means for drawing or pumping it. The size of the bucket or pump, and the power applied, will determine the exact amount of water obtained per hour, and the cost of obtaining it.

"The sooner this law is universally recognized for ventilation, the sooner will ventilation arrangements be generally successful.

"It should be further remarked as of great importance in arranging steam pipes for heating air in its passage to flues, that the pipes should not block up the flues, but should be placed in an enlargement or chamber, so that the aggregate area through and among the pipes shall be equal to the area of the flue, or even 10 per cent. greater. Moreover, the pipes or heaters should be so arranged that no air will pass without coming in contact with the heated surfaces. A baffled passage, causing the filaments of air to assume a tortuous course among the pipes, is the proper one. If the above conditions are fulfilled and properly applied, there seems hardly any limit to which ventilation may be carried in steam-heated buildings."

An interesting account of the application of steam coils to produce a ventilating current is given in a description of the heating and ventilation of the library building of Columbia College, New York, contained in the *Sanitary Engineer*, of June 28, 1883, from which is taken, by permission, the following account and illustration :

The ventilation was arranged by the architect, Mr. Haight, in accordance with the suggestions of Professor Trowbridge.

The system of heating is by indirect radiation from surfaces heated by low-pressure steam. The radiators are arranged as shown in Fig. 7.

In two of the large lecture rooms steam coils are placed at the base of the exhaust flues to induce an upward draught. "In each room there are four fresh-air inlets, each measuring 12″x20″, or equivalent dimensions, less the obstructions of the register. The steam coils in these four inlets have a combined heating surface of 720 square feet. In one room all four hot-air registers are near the ceiling (10 feet from the floor to the bottom of the register; the room is 15 feet high), but in the other room three of them are near the floor. The latter have sheet-iron screens in front of them, 8 inches larger than the register, and the same distance from the wall, to protect persons sitting in front of the register from the direct current. They are turned back to the wall on the end toward the exhaust flues, to direct the current away from the latter."

The outlets in both rooms are at the outside corners, at the floor level, into large circular flues in the corner turrets. The accompanying plan and section, Figs. 8 and 9 make clear the location and size of the heating coils and the air passage through and around them.

The full size of the main outlet from the room into each turret is about 32″x38″. This may be reduced as desired by a common register valve, which, however, is kept locked and under the control of the

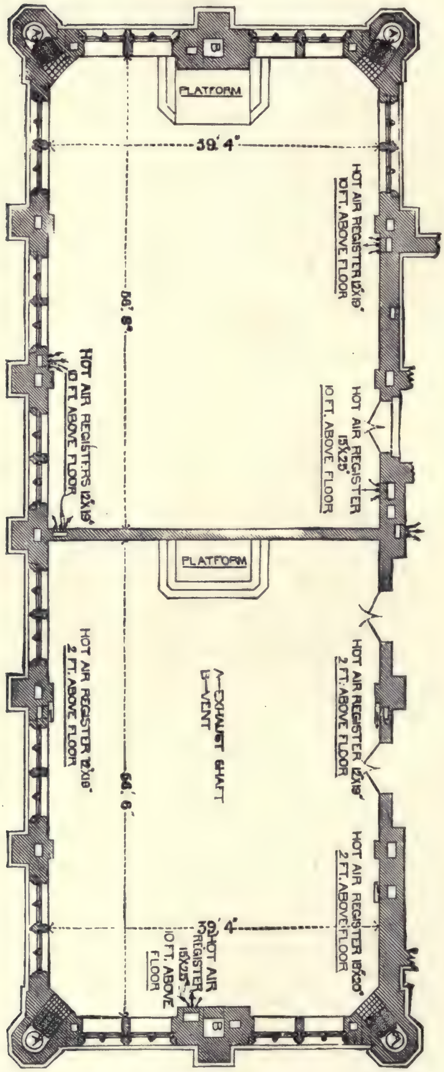


FIG. 6.—PLAN OF LECTURE ROOM, SHOWING VENTILATING SYSTEM.

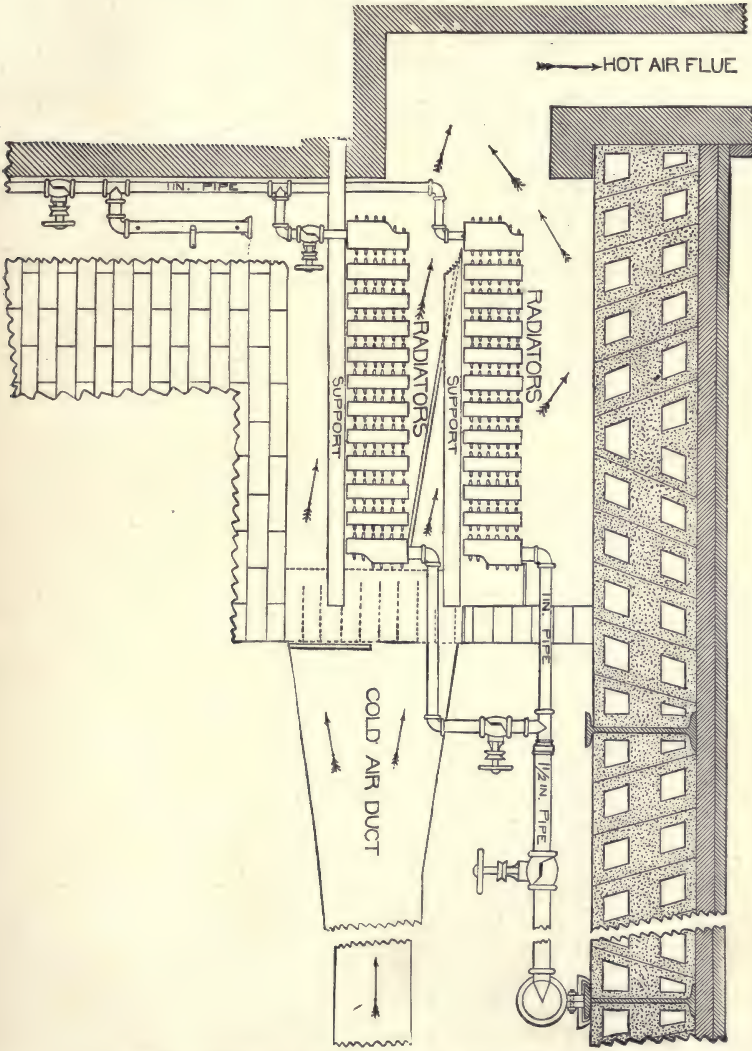


FIG. 7.—SECTION THROUGH COIL BOX IN CELLAR.

janitor. The arrangement of these coils was designed by Professor Trowbridge. They consist of three stacks of vertical 1-inch pipes, arranged in quincunx order on bases 1′x22″, and about 5 feet high. The rows perpendicular to the register are separated by sheets of tin, designed to serve as secondary radiating surfaces, thus largely increasing the efficiency of the coils. Horizontal sheets also are fitted over the pipes at intervals of 1 foot. The pipes fill the lower back part of the passage into the flue, but a considerable unoccupied portion remains above and in front of them, as shown by the plan, and section perpendicular to the register. The floor between the coils and register is tiled; the register is fastened only by a few screws, so that it may be easily removed to clean out the dust in front of and among the coils.

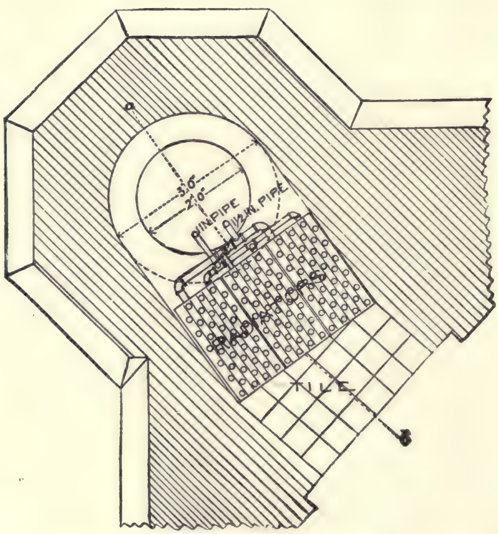


FIG. 8.—PLAN OF COIL AND EXHAUST SHAFT IN CORNER TURRET.

The total heating surface of the three stacks of pipe in each corner outlet is 650 square feet. The steam supplied to these pipes is not from the low-pressure system (the maximum pressure of which is 10 pounds), but has a maximum pressure of 50 pounds.

The smaller circle in the turret (Fig. 8), indicates the size of the flue up to this (the first) story, when it is increased to the size indicated by the larger circle. Above the larger outlet at the bottom is a smaller one directly above (10 feet above the floor), into the same

large flue, designed as an auxiliary outlet for a natural circulation. By these means it is calculated that the air in the rooms may be changed every 15 minutes.

Extensive use of steam coils in aspirating flues is also made in the Johns Hopkins Hospital, in Baltimore. In this case a certain part of the efficiency of some of the steam coils is lost, owing to the fact that they are placed high in the shafts above the entrance into the shafts of the upper air ducts, which are the ones which will do most of the work in warm weather. This loss might have been avoided by bringing these flues down to the base of the aspirating chimney, at which point the accelerating coils might then have been placed, with the result of obtaining a longer column of heated and rarified air, and a correspond-

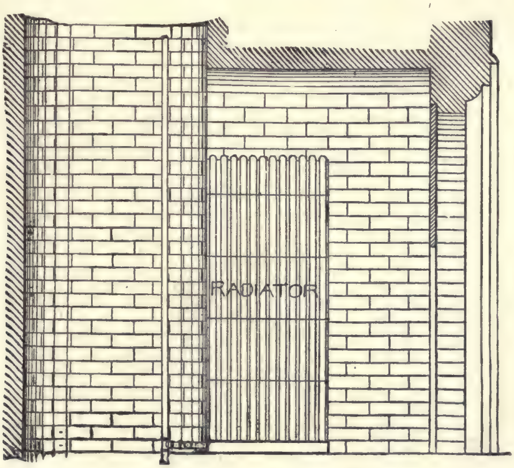


FIG 9.—SECTION THROUGH *a b*.

ing increase of power. To do this, however, would have increased the cost of construction to such an extent that it was thought better to accept the slightly increased cost of running the present apparatus for the few days during which it will be required.

The use of some form of fan or blower is a favorite method with engineers for producing currents of air for purposes of ventilation or of heating. They have been used for this purpose in mines for over 400 years, and, while engineers differ as to their relative economy and utility for this purpose as compared with the direct application of heat in one or more of the vertical shafts of the mine, which is thus converted into a chimney, the tendency for the last

30 years has been decidedly towards increased use of fans for ventilation of mines, and some very large ones have been put in place for this purpose.

Heating engineers also often wish to use the mechanical power of a fan or blower to force the air to be supplied over a centralized collection of radiating surface, thus saving the cost of long mains and returns, and, in the case of large buildings, enabling them to cheapen the cost of the plant. A lower bid for heating and ventilating apparatus does not, however, prove that the system is a cheaper one. If power is not employed for any other purpose, so that machinery must be specially provided to run the fan and the cost of attendance charged to it, it may be very expensive.

The use of forced ventilation by means of a fan or blower is especially useful in theaters, churches and assembly halls where large numbers of people are to be gathered for a comparatively short time, in workshops and factories of certain kinds for the removal of dusts and vapors, in tunnels and in mines, especially in coal mines ; and in large hospitals and asylums, not so much for continuous use as to provide the means of flushing out the wards with air, and of securing the movement of air required at those times when the external air is but a few degrees below 70° F., and when, consequently, the aspiration power of chimneys is much diminished.

As applied to theaters and halls of assembly, the fan is usually employed for forcing air into the room on what is called the *plenum* system, and illustrations of its application in this way will be found in the descriptions of the Hall of the House of Representatives in Washington, of the School of the Sorbonne in Paris, and of the Vienna, Frankfort, and New York opera houses, and of other buildings the plans of which are given in subsequent chapters.

The use of an aspirating fan in such rooms or buildings is not, as a rule, desirable.

For buildings which are constantly occupied, such as hospitals, asylums and prisons, the fan is an useful adjunct to provide for daily flushing and for occasional conditions of the atmosphere in the spring and autumn, but it is not desirable to so arrange it that its working is a necessity to obtain heat or change of air in cool weather. Fans are kept constantly running in some of the larger insane asylums in this country, as, for example, in the New York Asylum at Utica, where two fans, each 12 feet in diameter, are employed for this purpose. The heating surfaces are, however, not so centralized in this asylum that the stoppage of the fans would cut off all the heat from the wards.

What is called the central hot-blast method of heating is not a desirable one for buildings of this kind.

The largest fans are those used in some coal mines. There is one 50 feet in diameter at the St. Hilda Colliery, South Shields. This fan can be driven at a speed of 50 revolutions per minute, at which rate it is estimated to move 200,000 cubic feet of air per minute. The use of fans in this connection will be referred to hereafter in speaking of mine ventilation.

A very important use of small aspirating fans is to remove dusts, or offensive or dangerous gases or vapors, produced in various processes of manufacture, by drawing them off through hoods placed close to the machines or vessels in which they are produced, so that such dusts or fumes are not allowed to escape into and contaminate the general air supply of the room. In this way many trades which would otherwise be disagreeable or dangerous to health may be so conducted as to be harmless, and the applications of this method are manifold.

When it becomes necessary to devise a plan of ventilation for a building already constructed in which it is difficult or impossible to provide aspirating flues and chimneys of sufficient size to act as outlets, and especially where steam or electric power is available, the use of one or more comparatively small aspirating fans placed in the ceiling, or in the upper half of a window, will often give very good results. In making such an application of the fan care should be taken to provide sufficient and properly distributed fresh-air inlets. This is a matter which seldom receives attention from the vendors of patent fans—who have often set them up without the slightest attempt to provide a fresh-air supply. Even more absurd than this is the supposition that ventilation is effected by placing small fans run by electro-motors in a room without providing any outlet, the effect being, of course, merely a stirring up of the air without effecting any removal or change. The noise made by fans or blowers becomes an important matter to be taken into account in selecting one to be used for the ventilation of a building. To move a given quantity of air the smaller the fan the greater must be its velocity, and the greater the velocity the greater the liability to produce an unpleasant amount of noise. The various modifications in the form of the case and blades of fans which have been and are the subject of patents, have comparatively little effect on the actual efficiency of the instrument, but may have considerable on the noise produced. For fans intended to deliver a large amount of air against comparatively low pressures, not exceeding that of 1 or 2 inches of water, comparatively large fans run at low speed and

nearly noiseless, appear to give satisfactory results. This is the sort of fan used in the House of Representatives at Washington, and in the Barnes Hospital, and is described and illustrated in a paper "On the conditions and the limits which govern the proportions of rotary fans," by Mr. Robert Briggs, published as an excerpt from the Minutes of Proceedings of the Institution of Civil Engineers, Volume XXX., Session 1869–70, Part II.

The proper proportioning of the ducts on each side of such a fan to the diameter of the fan itself is essential to obtain the best results, and changes in the size of such ducts, where the supply of air is to remain constant, must result in loss of efficiency.

The table on the opposite page relates to rotary fans of comparatively large size and low speed, and is taken from the paper by Mr. Robert Briggs, above referred to. Such fans can move large quantities of air economically, but at low pressure only, usually not exceeding that of 1 or 2 inches of water.

The following table is taken from a recent catalogue of the Buffalo Forge Company:

Number of Blower.	Height of Blower.	Size of Outlet.	Diameter and Base of Pulley.	Ordinary Speed.	Horse-Power Eng.	Cubic Feet of Air per Minute Delivered at 1 Ounce Pressure.
48	52-inch	16¼x16¼	10x 8	690	2.3	8,740
49	60 "	18 x18	11x 9	623	3.0	11,000
50	70 "	21½x21½	12x10	522	4.0	15,280
50½	80 "	24 x24	12x10	450	5.4	19,900
51	90 "	27 x27	14x10	414	6.7	25,900
52	100 "	30½x30½	16x12	370	8.4	32 500
53	110 "	34 x34	18x13	323	10.6	39 300
54	120 "	37¾x37¾	20x14	296	13.0	49,161
55	130 "	40½x40½	22x16	275	15 0	57 720
56	150 "	48½x48½	26x16	224	20.0	81,120

For combinations of these blowers with a heater containing steam pipe forming a hot-blast apparatus, the same company gives a table which allows the following amount of heating surface stated in square feet—viz., for No. 50, 651; for No. 51, 869; for No. 52, 1,086; 53, 1,521; 54, 1,955; 55, 2,390; and for 56, 3,042 square feet.

As it will usually be found advisable to run the fan at about 75 per cent. of the speed indicated in the column headed "Ordinary Speed" in the above table, and as the amount of air delivered will be diminished by this, and also in most cases by friction, it is not safe to

FANS TO BE USED IN THE VENTILATION OF BUILDINGS OR MINES.

Diameter of Fans.	Revolutions per Minute.	Quantity of Air Delivered per Minute, Corresponding to Number of Revolutions and Pressure.*	Pressure, Difference between Inlet and Outlet of Fan Corresponding to No. of Revolutions taken.*	Horse-Power Required to Deliver the Quantity of Air at Given Pressure.	Dimensions of Pulleys.† Number of Pulleys.	Diameter of Pulleys.		Width of Belt Demand'd.		Proper Sectional Area of Delivery Air Duct or Passage.‡
Ft.	Number.	Cubic Feet.	Water Col. in Dec	H. P.	No.	Ft	In.	Ft.	In.	Square Ft., Dec.
16	62½ to 125	102,500 to 205,000	0.31 to 1.23	7½ to 59	2	8	4	1	3	160.8
14	70 " 140	80,000 " 160,000	" " "	5¾ " 46	2	7	6	0	10	113.2
12	83 " 167	57,500 " 115,000	" " "	4⅛ " 33	2	6	9	0	8	90.5
10	100 " 200	40,000 " 80,000	" " "	2⅞ " 23	2	5	2	0	6	62.8
8	125 " 250	25,500 " 51,000	" " "	1⅞ " 14¾	1	4	0	0	8	40.2
7	140 " 280	20,000 " 40,000	" " "	1½ " 11½	1	3	6	0	6	28.3
6	167 " 333	14,400 " 28,800	" " "	1 " 8¼	1	2	8	0	5	22.6
5	200 " 400	10,000 " 20,000	" " "	¾ " 5¾	1	1	10	0	5	15 7
4	250 " 500	6,400 " 12,800	" " "	½ " 3¾	1	1	4	0	4	10.05

* Double the quantity of air will be delivered each minute if the resistance to discharge or suction is brought down to one-half the pressure given in the pressure column, and the pressures may be increased (the number of revolutions of the fans remaining constant), by closing partly the inlet or outlet, the quantity of air delivered being gradually diminished until the inlet or outlet be entirely shut off, when the pressures will have risen to double those stated in the table.

† The dimensions of pulleys and belt refer to the largest capacity of the fans given in the table, it being supposed that it may be desirable to range from the lowest quantity and pressure to the highest in each case.

‡ The sectional area of the inlet or suction air duct or passage should exceed the areas given by 1.4 time, to allow a fan to produce its fullest effect. It has been found, when it was inconvenient to make the air ducts or channels of full sectional area to the end of a system of distribution, by enlarging them 0.025 per foot of length, so that outlets and channels, at the distance of 400 feet, were provided with double sectional areas, that the falling off of pressure was satisfactorily compensated for at the more distant outlet. It is obvious this rule will not apply to very small air passages. When the relationship of quantity and pressure corresponds to that given in the table, and it is never expected that a larger quantity will be required at a reduced pressure, the sectional area of the delivery air duct may be reduced one half, or nearly to that extent. The sectional area given admits the passage of double the quantity of air at one-half the pressure The frictional resistances of the sides of a duct are so considerable, that the largest duct possible should always be used, even when somewhat in excess of the dimensions given as to be desired.

count on obtaining much more than half the amount of air indicated in the last column.

If we take No. 54, a 10-foot blower, with an outlet of about 9.9 square feet, it would require a velocity of the current through this outlet of 82 feet per second to supply the 49,161 cubic feet of air assigned as the capacity of this blower.

Such a velocity, if obtainable, involves great loss of power by friction. For the same work Mr. Briggs' table would allow an outlet of about 60 square feet, giving a velocity of about 14 feet per second.

The use of the force contained in compressed air has thus far not been employed especially for ventilation purposes, although it has incidentally been of value in tunnel construction where drills or cutters driven by compressed air have been employed, since the air escaping from the machines working at the face of the rock forces backwards and outwards the air fouled by powder smoke, and by the respiration of the workmen. If, hereafter, it shall be found expedient to furnish from a central point compressed air as a means of rendering stored force available at distant points, it would be quite possible to use it in the form of a jet to induce motion in a comparatively large column of air. The steam jet has been occasionally used in this way, but it is not an economical method of moving considerable quantities of air.

A small stream or jet of falling water may be used on the same principle as the steam jet to induce movement of a column of air. An apparatus on this principle is connected with the lecture room of Pettenkofer's Laboratory of Hygiene in Munich. It consists of an U-shaped galvanized-iron tube, the upper extremity of one arm opening to the external air, and the upper extremity of the other arm opening into the hall. A water pipe, with nozzle pointing downward, enters each branch of the tube near the top, the flow being controlled by stop-cocks outside of the tube. The direction of the current of air in the tube depends upon which stop-cock is opened, so that it will either inject air into, or draw it from the hall. A small pipe at the bottom of the U permits the fallen water to run off.

CHAPTER IX.

EXAMINATION AND TESTING OF VENTILATION.

If we wish to know whether a room or building is sufficiently and satisfactorily ventilated, and if not so ventilated, the cause of the deficiency, we must ascertain the condition of the air contained in it as regards odor, presence of suspended matters, and of gases or vapors not found in perceptible amounts in the normal atmosphere, and especially as regards the proportions of carbonic acid and moisture contained in it as compared with those found in the immediate sources of supply.

The carbonic acid test is the one chiefly relied upon to determine the relative amount of impurities that are being added to the air, and whether the distribution of the fresh air is such as to ensure its thorough mixture with the mass of the air within the room.

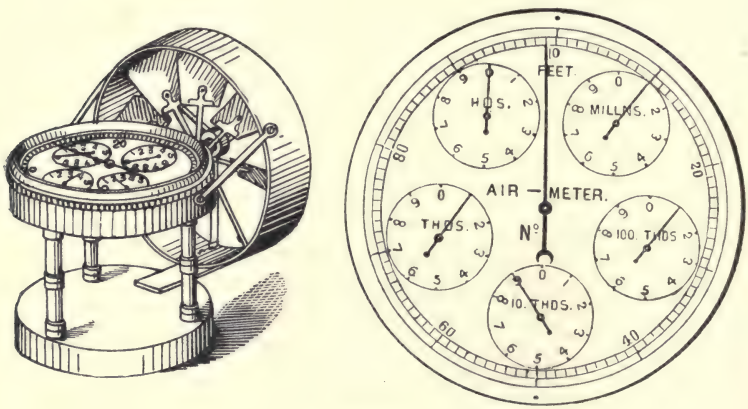
But we also need to know the amount of floor space and cubic space contained in the room, the number of persons in it, or to be supplied, whether its occupation is temporary—that is, for an hour or two only, or permanent, that is, for six hours or more in succession—the amount of fresh air introduced per hour, and the position, direction and velocity of the air currents produced within the room, and their effect upon the persons occupying it; and it will often happen that these data, or a part of them, are the only ones we have from which to judge, seeing that the chemical tests are not available.

In hospital wards, soldiers' barracks, or in dormitories of any kind, as in common lodging rooms, tenement houses, prison cells, etc., and in school rooms, the determination of the number of square feet of floor space, and of cubic feet of air space to each person is an important item in forming a judgment as to the probable sufficiency of the means of ventilation.

Having obtained the dimensions of the room, the next thing is to note the position and size of the openings in the room which are either intended to serve, or which may serve, as inlets and as outlets, and to determine the direction and rapidity of the movement of the air through them. If there are distinct and special outlets, as by flues provided

for the purpose, it may be sufficient to measure the amount of air passing through these outlets or flues, since the amount of incoming air must be nearly or quite the same. The quantity of air passing through a given opening is found by multiplying the area of the opening stated in square feet or fractions of a foot by the velocity of the current stated in lineal feet per minute, the product being the number of cubic feet of air passing per minute.

The velocity of the air current is determined by instruments known as anemometers, pressure gauges or manometers. Those which indicate the velocity by registration of the pressure exerted are sometimes called static anemometers.



THE DIAL.

FIG. 10.

Dynamic anemometers, or air meters, are those so constructed that the velocity of the air current can be determined by the rate at which it causes a very light propeller-like wheel placed in its course to revolve. The number of revolutions of this wheel are recorded in feet or meters upon a dial with which it is connected by an arrangement of cogs, and from this dial the rate at which the current is passing over the instrument can be read in a few minutes.

For the study of ventilation by anemometric methods, the dynamic forms of the instrument are those most commonly employed, though for certain purposes, as will be explained hereafter, the static anemometers are sometimes used.

Of the dynamic anemometers, a variety of different forms exist, though the principles involved in them all are, in the main, the same.

The instrument usually employed in this country and in England is that manufactured by Mr. L. Casella, of 174 Holborn, Bars, London, E. C., and it is in all probability as accurate and reliable in its indications as any on the market.

The instrument consists, as Fig. 10 shows, of a dial with revolving indicators, connected by clock-works with the propeller-like fan that revolves when exposed to a current of air. According to the rate at which the fan revolves, a velocity varying from 1 foot to 10,000,000 feet in a given time can readily be determined from the indications on the dial in a few minutes.

Each division passed by the long hand on the large circle represents 1 foot traversed by the current of air. In setting down a reading of the hands, the long hand takes the units and tens places. The five other hands follow, respectively.

Example :

	Milns.	100 Thds.	10 Thds.	Thds.	Hds.	Long hand.
Reading of the diagram........	1	1	9	1	0	9 9

Any one not familiar with metric dials must observe that the figures read rationally; thus, if the feet hand is at 99, the hundreds hand will be near the figure it is approaching. This figure must not be taken, but the previous one that is passed.

A catch is placed on the rim of the instrument to enable the observer to throw the indicating wheels in or out of gear from the fan, for the purpose of taking short observations with accuracy.

TO USE THE INSTRUMENT.

Press the catch home to the right hand, and the fan will revolve without moving the indicators on the dial. Now take a careful reading from the face of the instrument and write it down; place the instrument in the air current and allow the fan to revolve freely for a short time, care being taken that the current strikes the fan *at right angles with its plane.* With a watch open let the instrument run freely until the second hand of the watch indicates a full minute when the anemometer is to be thrown into gear by pressing the catch to the left. At this instant the hands on the dial begin to record and continue until the instrument is again thrown out of gear, which in practice is usually after exactly one minute. Another reading from the dial is

now carefully made and the difference between this reading and that made before the instrument was thrown into gear gives the number of feet of air that has passed over the instrument during the time for which it was recording. For example :

Reading before the instrument was in gear.... ....10,685 feet.
Reading after instrument has been recording for one minute.......12,432 feet.
Number of feet of air passing over the instrument in one minute.. 1,747 feet.

These figures, however, are simply those taken from the dial, and as every instrument, no matter how delicately constructed, presents more or less friction, there must be a correction for this. This correction varies with different instruments, so that for each instrument a certain number of feet must be added. For example, if in the anemometer from which the above readings were taken there was an additional correction of 25 feet for each minute that it had been running, the velocity of the current of air tested would be 1,747 + 25 = 1,772 feet per minute.

In using the instrument care must be taken that the fan is not bent or injured, and that the bearings are all properly cleaned and oiled.

Where the instrument is employed for determinations of quantities greater than those concerned in the study of ventilation, Mr. Casella has prepared the following table:

TABLE SHOWING THE NUMBER OF MILES PER HOUR AT VELOCITIES PER MINUTE.

Feet per Minute.	Miles per Hour.	Feet per Minute.	Miles per Hour.
10	.113	600	6.818
20	.227	700	7.954
30	.340	800	9.090
40	.454	900	10.227
50	.568	1,000,	11.363
60	.681	2,000	22.727
70	.795	3,000	34.090
80	.909	4,000	45.454
90	1.022	5,000	56.818
100	1.136	6,000	68.181
200	2.272	7,000	79.545
300	3.409	8,000	90.909
400	4.545	9,000	102.272
500	5.681	10,000	113.636

The form of dynamic anemometer most frequently employed in Germany is that of Combes and Recknagel. In general principle it is the

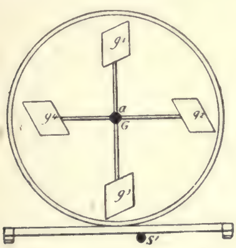
same as that of Casella, but is by no means an instrument of such elegant appearance.

In general the same can be said for this apparatus as has been said for the Casella instrument. Its construction can best be understood by the figures shown below.

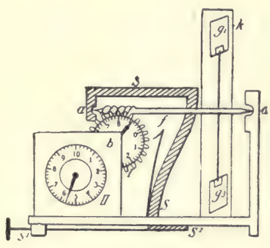
In general it consists of a very light propeller-like fan or wheel the revolutions of which are recorded in terms of meters and fractions of meters upon a dial with which it is connected by a system of cogs.

Still another application of the same principle is employed in the anemometer of Robinson, in which, instead of a revolving propeller-like wheel or fan, there are cupped radii of a circle.

With each anemometer as it comes from the manufacturer there is usually a correction which is to be added to the readings obtained from the dial in order to obtain the exact result. This correction is necessitated by the friction experienced by the gearing of the apparatus while running.



COMBES' ANEMOMETER.



RECKNAGEL'S ANEMOMETER.

With use the bearings of the apparatus gradually become worn, so that it becomes necessary to control the correction from time to time by testing the anemometer.

A variety of methods are employed for this purpose, but a simple test, though not without possible errors can always easily be made as no instrument but a tape line and a large closed room — the larger the better — is necessary. A track around the room of 100 feet or any other convenient distance is measured. Then holding the anemometer at arm's length on a small rod at right angles to the way you face, go around the track in different directions and at different speeds, noting the error, whether fast or slow. By reversing the direction of motion about the track, the effect of local currents in the room is eliminated and the danger of setting all the air in motion in one direction around the room is avoided. If an anemometer is

held before the operator, or near enough to his body so that his motion will affect the air which the anemometer is passing through the experiment will not be reliable. There are other methods, but they require special contrivances.*

Of practical importance to those wishing to obtain an anemometer is the advice given by Mr. Gieseler in the communication referred to in the foot note. He states: "Those with agate bearings will not only wear longer and run with less resistance, but the possession of such a bearing is of itself an evidence of better workmanship and material than is to be expected in those which are not so fitted, which, as a rule, are not worth purchasing at any price."

In the study of ventilation the only use that is made of the static forms of anemometers is as constant indicators of the pressure of air currents, which pressure as indicated upon the face or dial of the instrument, corresponds with a certain velocity that has been previously determined by comparison with a correct dynamic anemometer.

If one has a dynamic anemometer with which to control and correct their static apparatus, it is a very easy matter to construct an instrument that can be fixed permanently in the course of the air current and give at all times fairly accurate indications of the velocity of the current that is causing the fan of the apparatus to deflect.

An anemometer that requires no special skill in its employment, and at the same time gives results which approximate so closely to those obtained through the use of more elaborate instruments as to make it of considerable value in rapidly judging the approximate amount of air passing into a room through the registers, may be easily constructed, as shown by the following figures.

The instrument is made of cork, paper and broom straws. It consists of an ordinary cork (*A*) from which is made to swing at the point *E*, a paper fan *c* suspended upon the arm *B*, which is simply a thin light broom straw. At *E* the arm *B* swings upon a fine cambric needle, so that there is very little friction, and the fan is caused to swing under the pressure of the lightest draught. *D* is a quadrant divided into equal parts. It is made fast to the cork *A*, and registers the distance which the fan *c* swings out of the line of perpendicular. By comparison with an exact instrument the values of the markings on the quadrant may be established, and these values recorded upon the different radii. These values being established, one has then but to insert

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* See *Sanitary Engineer*, March 10, 1888.

For a more extensive discussion upon The Testing of Anemometers see *Sanitary Engineer*, July 13, 1889. Communication from Mr. E. A. Gieseler.

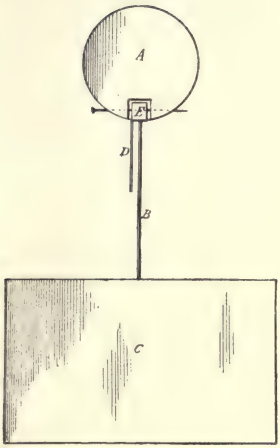

FIG. 11.

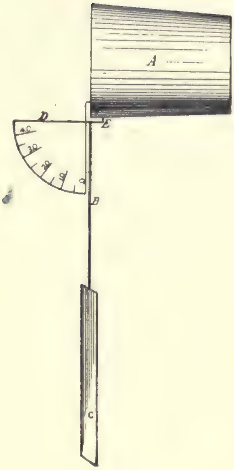

FIG. 12.

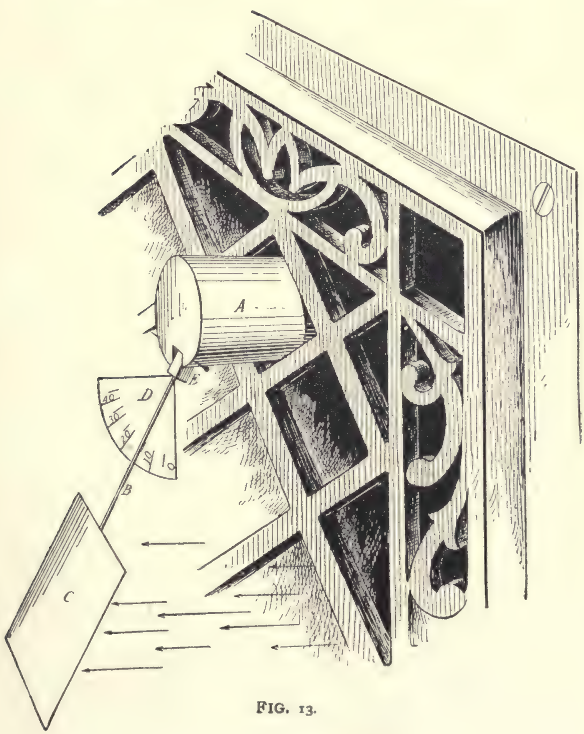

FIG. 13.

the cork A into an opening on the face of the register, and observe the distance which the incoming air causes the fan c to swing from the perpendicular. This distance corresponds, as may be seen upon the quadrant, to the pressure of the air at different velocities. The clear opening of the register being known, it is then easy to calculate the amount of air expressed in cubic feet per second passing through the register.

Fig. 11 represents the instrument in profile.
Fig. 12 " " " seen from the front view.
Fig. 13 " " " showing deflection of the fan (indicator) under pressure of incoming air.

A somewhat more elaborate form of the same apparatus has recently been devised by Fuess, of Berlin. It is intended to be placed permanently upon the wall surface of a flue, with its fan projecting in-

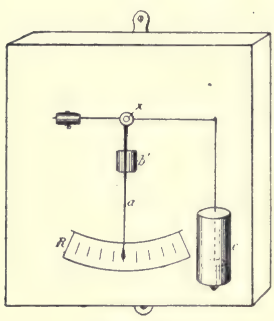

FIG. 14.

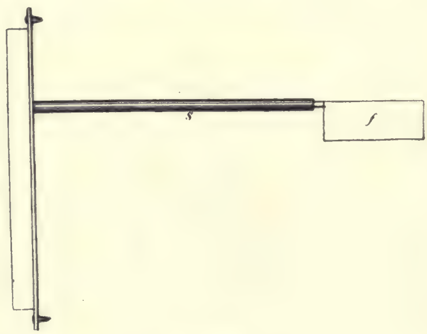

FIG. 15.

side and exposed to the action of the currents passing up the flue. The deflections of the fan are indicated by a pointer that traverses an arc upon the face of the apparatus.

By the use of this apparatus one can see at a glance upon entering a room, in which the apparatus is placed, the velocity of the air passing up the flue, as indicated by the position of the pointer on the arc. The apparatus is seen in Figs. 14 and 15.

These show a transverse section of the knife edge that passes through the hollow tube s, and carries on the face of the apparatus the pointer a, and on the other end that projects into the flue the fan f. b and b' are sliding weights by which equilibrium and adjustment are maintained. c is a vessel containing glycerine, in which floats a counterpoise for the weight b. R is the arc traversed

by the pointer a, and marked at intervals with lines indicating the velocity of a current that causes the different degrees of deflection.

In the use of anemometers there are several points to be borne in mind.

The apparatus must always be clean and well oiled. The plane of its revolving fan must be at right angles to the direction of the air current, and must be free in the current so as not to be influenced by eddies caused by the friction of the air against surrounding objects.

When used for the determination of currents of air passing up flues or through registers, one observation is not sufficient for accuracy, but a mean of several observations made at the corners and center of the flue or register must be taken.

The results should be those obtained after an exposure of the instrument to the current of not less than one minute for each observation.

To determine the direction of the air currents within the room, smoke is commonly used. This smoke may be produced by burning tobacco, or cotton velvets, or lamp wick saturated with benzoin, etc., or by igniting a little slightly moistened gunpowder. The fumes of nascent muriate of ammonia are in some respects preferable to smoke, since they are of the same temperature as the air and can injure nothing in the room. They are produced by pouring a little liquor ammoniæ into a capsule or saucer and surrounding this with a sheet of common blotting paper about 6 inches wide, pinned into the shape of a shirt cuff and saturated with diluted hydrochloric acid. Filaments of floss silk suspended from a rod, furnish a delicate test for air currents. Toy balloons are rarely of much use for this purpose and the flame of a candle is not sufficiently easy to move.

For producing smoke to test direction and velocity of air currents Pettenkofer uses cotton lamp wick, which has been boiled for several hours in a 6 per cent. solution of nitrate of potash, then thoroughly dried at 100° C., then steeped for several hours in an alcoholic solution of gum benzoin, and then dried at ordinary temperatures.

While observations as to the direction and velocity of air currents in a room can give only approximate information as to the condition of the ventilation, and should always be supplemented by the chemical method, they are, nevertheless, much more satisfactory than opinions as to whether the ventilation of a given building is good or bad, founded not on any tests as to quality or quantity of air, but on personal sensations, which in most cases are due rather to temperature than anything else. People are apt to suppose that a cool room must be a well-ven-

tilated room and that when they are too hot the air must be impure. It is true that an overheated room is not a properly-ventilated room if the temperature of the external air is below 70° F., for one of the objects of ventilation is to produce a comfortable temperature; but hot air may be pure, and cool air dangerously impure. As was mentioned in the section on quantity of air required, the normal sense of smell is an excellent means of judging of the sufficiency of ventilation of a closed room occupied by human beings, but to have this sense normal the person must come in from the fresh outside air, and not have remained in the room more than a very few minutes.

The amount of ventilation going on in an apartment at any moment may be determined either by direct measurement of the velocity with which the air enters and leaves through openings especially designed for its entrance and exit, or by a systematic series of chemical analyses of the air made at stated intervals for a certain period of time.

If the method of direct measurement of the velocity of the incoming and outgoing currents is selected, the procedure is a simple one, though the results thus obtained can only be considered as approximate, because of the leakage through cracks about doors, windows, etc., where it is impossible to measure accurately the amount of exchange going on.

In the determination through the aid of anemometers the exact areas of the inlet and outlet for air entering and leaving the room are to be ascertained by measurement, and by means of the anemometer the velocity of the currents passing through them is determined for a given length of time, one minute being the time usually selected. By dividing the result of the observation by 60 or multiplying it by 60 we obtain the amount of air entering and leaving the room, through the ventilators, per second or per hour. From the cubic capacity of the room it is then easy to determine the number of times per hour the whole volume of air is being renewed.

In this method all windows and doors opening into the room must be closed, and only those openings intended for the passage of air be allowed to remain open.

In measuring the velocity of these currents it is customary to make five observations at each opening. The anemometer is to be held at the center, and at four diametrically opposite points near the periphery of the opening. Each determination is to be for one minute, and an average of the five observations taken as the velocity of the whole current per minute.

Example.—The room measures 10'x12'x10' = 1,200 cubic feet capacity. Observations at either inlet or outlet ventilators as follows:

Center	= 64	feet per minute.
Top edge	= 58	" " "
Bottom edge	= 59	" " "
Right side	= 59	" " "
Left side	= 60	" " "
	300 ÷ 5 = 60	feet per minute average.

By measurement our ventilators are found to have a clear transverse area of 1 square foot. We have, therefore, 1 square foot area × 60 feet per minute velocity = 60 cubic feet per minute passing through the opening; for one hour we should, therefore, have 3,600 cubic feet passing through. The capacity of our room is 1,200 cubic feet. Therefore, this volume of air is being completely renewed at the rate of three times per hour as shown at the air inlets or outlets where it is possible to measure directly the velocity of the incoming currents.

The chemical method suggested by von Pettenkofer for the study of ventilation has the advantage over the method just described, in determining the entire exchange of air going on; including not only the amount passing in and out through the ventilators, but likewise that escaping through cracks about the doors and windows. It gives, therefore, much more exact results than can be obtained through direct measurement.

It is based upon the fact that if in a closed room we have any easily recognizable gas, the amount of fresh air entering the room in a given time may be determined by the dilution experienced by the gas in this time.

As a characteristic gas Pettenkofer recommends carbonic acid. He closes all openings into the room and then artificially generates an excessive amount of this gas in the air of the room. After thoroughly mixing by means of fans, the amount of carbonic acid present is determined. The ventilators are then to be opened and at equal intervals for a given time analyses are again made and from the diminution in the amount of the gas present the rate of inflow of fresh air is determined. As source for the production of the carbonic acid stearine candles of good quality are recommended. Such candles when burning give off about 2.764 grams or 1.404 litres of CO_2 per gram of candle, and burn at about 9.6 grams per hour.

In the apartment to be studied a number of such stearine candles are to be burned. Their number and the time necessary for the pro-

duction of an excess of CO_2 is to be calculated from the preceding figures for this rate of production. Or, as has been recommended by Petri (Zeitschrift f. Hygiene, Bd. VI.), fluid carbonic acid may be liberated in the room. When the experiment is begun, the air of the room should contain this gas in the proportion of about 5 to 6 parts per 1,000, the exact amount being determined.

The doors and windows are kept closed, and samples of air are to be taken from about the center of the room at intervals of 30 minutes for one hour after the ventilators are opened.

In taking these samples, it is well to obtain them through a tube passing through a small opening into the center of the room. The tube may pass into the room either through the keyhole of the door or through an opening made at the floor level. The samples of air may then be drawn by means of an aspirator into flasks intended for the purpose, without the door to the room being opened.

When the necessary number of samples have been collected and analyzed, the calculation for the rate at which ventilation has been going on is made from the formula of Seidel:

$$x = 2.303 \times m \times log. \frac{p_1 - a}{p_2 - a},$$

in which

m = cubic contents of the room.
p_1 = amount of CO_2 present at the beginning of experiment.
p_2 = " " " " "
a = " " in open air.
x = amount of air which has passed into the room.

Example.—By the method of analysis for the determination of carbonic acid, it was found that the air of a room contained:

At the beginning — 3.590 % CO_2.
After 30 minutes — 3.170 % CO_2.
After 60 minutes — 2.806 % CO_2.
Open air — 0.350 % CO_2.
Cubic contents of room, 1,200 feet.
x = amount of ventilation going on.

For the first half hour:

$$x = 2.303 \times 1{,}200 \times log. \frac{3.590 - 0.350}{3.170 - 0.350} = 2.303 \times 1{,}200 \times 0.06032$$

= 166.7 cubic feet of air passed in during first half hour.

And for the second half hour:

$$x = 2.303 \times 1{,}200 \times log. \frac{3.170 - 0.350}{2.806 - 0.350} = 2.303 \times 1{,}200 \times 0.05994$$

= 165.7 cubic feet of air.

Therefore, for the entire hour, we have $166.7 + 165.7 = 232.4$ cubic feet of air passing into a room of 1,200 cubic feet capacity. At this rate the entire volume of air in the room would require 5.2 hours for its complete removal, a rate of ventilation quite inadequate for purposes of comfort.

This method meets its greatest application in apartments which depend for their air supply entirely upon that afforded through the channel of "natural ventilation." Though more exact than the actual measurement of the amount of incoming air, still the detail involved in its performance renders it of less universal application.

It should also be borne in mind that when this method is used for determining the amount of ventilation of rooms provided with air inlets, provision must be made for opening and closing these inlets by cords from without, for the accuracy of the results will, of course, be destroyed if doors be opened.

For the determination of the number of cubic feet of air required per head per hour in inhabited apartments, De Chaumont proposes the following formula:

$$\frac{e}{p} = d$$

in which

e = amount of CO_2 exhaled hourly by adults expressed in cubic feet.

p = the limit of admissible impurity.

d = amount of fresh air required per hour.

Taking 0.6 cubic feet as the average amount of CO_2 exhaled by an adult in one hour, and 0.0002 as the exponent of admissible impurity from human exhalation, we have $\frac{0.6}{0.0002} = d = 3{,}000$ cubic feet, the amount of fresh air which should be delivered to each adult in one hour.

The actual amount of fresh air being supplied may be calculated by substituting for the admissible impurity the actual impurity. Thus, suppose we find the air to contain 0.7 parts CO_2 in 1,000, we then have $\frac{0.6}{0.7} = 857$ as the number of cubic feet of air being supplied per hour.

Or if the proportion of carbonic acid present in the air of a room be required and the rate of delivery of the air be known, it may be calculated from the same formula, thus, substituting in the above

formula p_1 as representing the actual amount of this gas present for p, which represents the admissible limit of impurity, we have

$$\frac{e}{p_1} = d, \text{ hence}$$

$$\frac{e}{d} = p_1.$$

Taking again 0.6 as the number of cubic feet of CO_2 exhaled per hour by adult individuals, and 1,200 cubic feet per hour as the rate at which air is entering the apartment, we have

$$\frac{0.6}{1,200} = 0.0005 \ CO_2 \text{ per cubic foot,}$$

or 5 parts in 10,000.

In all these formulæ the value of e must be changed with different conditions: For children it averages 0.4; for adults under ordinary conditions it is, as stated, 0.6; for adult males alone, as for example, soldiers in barracks, 0.72 is suggested as the average hourly exhalation of carbonic acid in cubic feet.

In discussing the relation of atmospheric moisture to ventilation, De Chaumont (Proc. Royal Soc., London, Vol. XXV., 1876–77, p. 11), states that an increase of 1 per cent. of humidity has as much influence on the condition of an air space (as judged of by the sense of smell) as a rise of 4.18 degrees of temperature in Fahrenheit's scale. This may be taken as a proof of the powerful influence exercised by a *damp* atmosphere, corroborating the conclusions arrived at by ordinary experience; and it follows that as much care ought to be taken to insure proper hygrometric conditions as to maintain a sufficiently high temperature. This is especially the case in the wards or chambers of the sick, in which regular observations with the wet and dry-bulb thermometers ought to be made; these would probably give a valuable indication of the ventilation either along with or in the absence of other more detailed investigations. Thus, a room at the temperature of 60° F. and with 88 per cent. of humidity, contains 5.1 grains of vapor per cubic foot; suppose the external air to be at 50° F. with the same humidity—88 per cent.—this would give 3.6 grains of vapor per cubic foot; to reduce the humidity in the room to 73 per cent., or 4.2 grains per cubic foot, we must add the following amount of external air:

$$\frac{5.1 - 4.2}{4.2 - 3.6} = 1.5,$$

or once and a half the volume of air in the room. If the inmates have each 1,000 cubic feet of space, it follows that either their supply of fresh air is short by 1,500 cubic feet per head or else that there are sources of excessive humidity within the air space which demand immediate removal.

In what would be termed "pure country air," carbonic acid is present in the proportion of about 3 parts in 10,000. In a crowded and confined space, such as the pit of a theater and in some school-rooms, its proportion has been found to rise to 30, 40, and even 100 parts per 10,000.

Pure carbonic acid gas may be present in air in a proportion as high as 150 parts per 10,000, without producing discomfort or giving any special evidence of its presence, as, for instance, in those establishments where sparkling mineral waters are bottled, or soda fountains are charged, or in vaults where champagne is bottled, in certain rooms in breweries, or in some celebrated baths and health resorts.

It is evident, therefore, that carbonic acid gas—in the proportions in which we find it in our worst ventilated rooms—is not in itself a dangerous impurity ; in fact, we have no evidence to show that in such proportions it is even injurious.

What, then, is the importance of this gas in relation to questions of ventilation ? and why do sanitarians lay so much stress upon the results of chemical tests of air with reference to this substance, and on what may seem very small variations in the proportions in which it is present ?

It is because carbonic acid is usually found in very bad company, and that variations in its amount to the extent of 3 or 4 parts in 10,000 indicate corresponding variations in the amount of those gases, vapors and suspended particles, which are really offensive and dangerous ; and also because we have tests by which we can, with comparative ease and certainty, determine the variations in the carbonic acid, while we have no such tests of recognized practical utility for the really dangerous impurities.

As a matter of convenience, therefore, we measure the carbonic acid, and thus get a measure of the extent to which ventilation is being effected. Of course, we must make sure that the circumstances of the case present nothing unusual, since, on the one hand, carbonic acid may be present in great excess, as in a soda-fountain-charging room, without indicating great impurity ; and, on the other, it is possible that the air of a room may be very dangerous from suspended organic particles, and yet have carbonic acid present in merely normal

amount. This will appear more clearly when we come to consider the ventilation of hospitals for infectious diseases.

But while the quantity of carbonic acid which is contained in some of our worst ventilated rooms is not injurious to human life, the amount of this gas present is nevertheless of very great importance in relation to ventilation, and very small variations in it—even so little as one ten-thousandth part—are often very significant, because we measure by it the quantity of organic impurities present, since we cannot conveniently measure these impurities themselves.

In most treatises on ventilation we are told that the best test for the presence of an undue amount of impurity in the air is the sense of smell. When a person goes from the fresh outer air into an inhabited room, and does not perceive any special odor, it is usually safe to assert that that room is well ventilated. But while this is true, it is necessary to have some other test which will be independent of individual peculiarities, and the results of which can be demonstrated to others. The man who has a patent sanitary stove, or an automatic ventilator, will rarely find any disagreeable odor in a room fitted with his appliances. The carbonic acid test for foul air depends upon the fact that when, as the product of respiration, the proportion of carbonic acid in a room increases from the normal amount of about 3 parts in 10,000 to between 6 and 7 parts in 10,000, a faint, musty, unpleasant odor is usually perceptible to one entering from the fresh air. If the proportion reaches 8 parts the room is said to be close.

To secure entirely satisfactory ventilation which will prevent this odor, the proportion of carbonic acid derived from respiration, or what is sometimes called the "carbonic impurity," should never exceed 2, or, at the utmost, 3 parts in 10,000 of the air in a room; that is, if the proportion in the fresh air be 4, that in the foul air must not exceed 7. The testing the amount of carbonic acid present is, although a simple operation, one which requires much care and precision throughout. In collecting the sample of air for examination, special precautions are required, since, if any one has his head too close to the jar, or if several persons gather around to see what is going on, the sample will show too high a proportion of carbonic acid.

For ordinary purposes a convenient method of testing the amount of carbonic acid is that of Smith, for which there will be needed six well-stoppered bottles, containing respectively 450, 350, 300, 250, 200 and 100 cubic centimeters, a glass tube or pipette graduated to contain exactly 15 cubic centimeters to a given mark, and a bottle of perfectly clear and transparent fresh lime water. The bottles must be perfectly

clean and dry. Having made sure that they are filled with the atmosphere which is to be examined, which can best be done by pumping into them a quantity of this air by means of one of the small handball syringes, which may be procured in any drug store, and taking care that none of your own breath is pumped in, add to the smallest bottle by means of the pipette, 15 cubic centimeters of the lime water, put in the cork, and shake the bottle. If turbidity appears, the amount of the carbonic acid will be at least 16 parts in 10,000. If no turbidity appears, treat the next sized bottle—viz., of 200 cubic centimeters, in like manner. Turbidity in this would indicate 12 parts in 10,000. If this remains clear, but turbidity is produced in the 250 cubic centimeter bottle, it marks about 10 in 10,000. The 300 cubic centimeter bottle indicates 8 parts, the 350 7 parts, and the 450 less than 6 parts. To judge of the turbidity, mark a small piece of paper on the inside with a cross in lead pencil, and gum to the side of the bottle on the lower part. When the water becomes turbid the cross will become invisible when looked at through the water. This will enable one to judge roughly of the amount of carbonic acid in the air. For more accurate analysis the processes can best be learned by spending about three hours a day, for three or four days, in a laboratory, working under the directions of a good chemist.

FIG. 16.

Another instrument, which is claimed to be the simplest and cheapest means of making an approximate estimate as to the proportion of carbonic acid contained in air, is one devised by Professor Wolpert, and called by him an air tester. This consists of a test tube, marked near the bottom to show the point to which it must be filled to contain 3 cubic centimeters. The bottom of this tube is whitened, and on the bottom is a black mark—or a date printed in black. Clear lime water is poured in the tube to the amount of 3 cubic centimeters, and the air to be tested is blown through this fluid until it becomes so opaque from the formation of carbonate of lime that the figure on the bottom of the tube becomes invisible. The air is blown through by means of a rubber bulb containing 28 cubic centimeters fastened in a glass tube, the free end of which dips beneath the surface of the lime water. See Fig. 16.

The number of times which this bulb must be filled and emptied measures the amount of air required to produce the opacity above

referred to, and a table which accompanies the instrument shows the proportion of carbonic acid which corresponds to a given number of fillings of the bulb. Thus, if the bulb has been emptied 40 times to produce opacity, the proportion of carbonic acid present is 10 parts in 10,000; if the bulb has been filled 50 times the carbonic acid is 4 parts per 10,000, etc. It is claimed that with this instrument the unskilled observer, after three or four trials, can estimate the proportion of carbonic acid present to within 1 part in 10,000, which is near enough for practical purposes. The chief precaution to be taken by the experimenter is to see that in filling the bulb with the air of the room he does not draw into it an undue proportion of air which he himself has just exhaled.

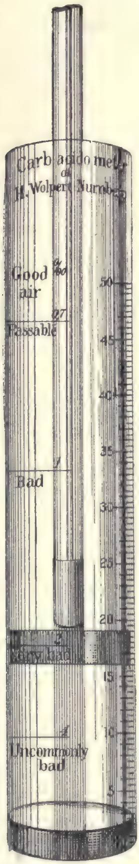

FIG. 17.

Comparisons of results obtained by the use of this instrument with those found by exact analyses of the same air show that it is extremely unreliable and in many cases the results can hardly be considered approximate. The reason for this is the impossibility of causing the same volume of air to pass through the fluid with each compression of the rubber bulb. If exactly the same volume of air were forced through the fluid with each compression there is no reason why fairly accurate results should not be obtained.

Another form of air tester, devised by Wolpert and known as a carbacidometer, is shown in Fig. 17. It consists of a cylinder graduated to 50 cubic centimeters on the one side and etched on the other side at the level of 10 cubic centimeters with the words "Uncommonly bad" and the figure 4; at 18 cubic centimeters with "Very bad" and the figure 2; at 33 cubic centimeters with "Bad" and the figure 1, and at 47 cubic centimeters with "Passable" and the figure 0.7. Within this cylinder slides a piston head which fits snugly with a rubber packing and is moved by a glass piston, through which is a capillary canal.

In the employment of the carbacidometer a solution of sodium carbonate is employed and phenolphthalein is the indicator used. These accompany each apparatus, packed in small capsules, each of which contains the proper weight of material. Directions for making the solution from these compounds likewise accompany each instru-

ment. When the solution is ready for use it is of a bright magenta color.

When a test is to be made 2 cubic centimeters of the red solution are placed in the cylinder and the piston is replaced and pushed gradually down upon it until the fluid begins to rise in the capillary canal. The piston is then gradually withdrawn until the center of the piston head is opposite the words "Uncommonly bad" and the figure 4. The apparatus is then shaken by a lateral swinging motion, the finger being held all the while over the outer extremity of the capillary opening in the piston for one minute. If at the end of this time no color change is seen the finger is removed from over the capillary canal, the piston is withdrawn a little further, to the mark "Very bad," and again shaken for one minute; if at the end of this time the color begins to fade, or fades away entirely, then the air under analysis contains approximately the amount of carbonic acid represented by the figure which accompanies the words opposite the head of the piston, in this case "Very bad" is equivalent to an air containing 2 parts of carbonic acid in 1,000 parts of air. If no disappearance of the color of the solution is seen when the piston is withdrawn until the head is opposite the mark indicating 50 c.c. on the cylinder, the air contains less than 0.7 parts CO_2 in 1,000 parts air, and is considered good air.

The minute details for the manipulation of the apparatus accompany each instrument.

A third form of apparatus devised by Wolpert, and known as a "continuous air tester," is, as the name implies, intended to register at all times the condition of the air in the room in which it is placed, just as a thermometer registers the respiration. This apparatus consists of a wooden stand, on the upper end of which rests a reservoir containing sodium bicarbonate solution, with phenolphthalein as indicator. Upon the solution is a float to which is attached a syphon of such caliber that it permits a drop of the solution to fall upon a cord which hangs in front of a porcelain scale once every 100 seconds. As the drop strikes the cord and slowly trickles down it, the cord takes on a red color, which color remains according to the amount of carbonic acid present in the atmosphere. This gas converts the carbonate into the bicarbonate of soda, with the ultimate disappearance of the color of the indicator. The point on the string at which the color disappears falls opposite a portion of the porcelain scale, on which are the words, "Pure," "Passable," "Bad," "Very bad," and "Uncommonly bad," which correspond in the order named to carbonic acid in 1,000 parts of air in the following proportions: 0.5 to 0.7, 0.7 to 1.0, 1.0 to 2.0,

2.0 to 4.0, and 4.0 or more. In the work of Bitter (Zeitschr. f. Hygiene, Bd. IX., 1890), this apparatus was compared with exact methods of analysis, and the results were so irregular that Bitter considers the apparatus little better than a toy, and of little or no hygienic value.

His comparisons were as follows :

TABLE.

Wolpert.	Exact Method.
Bad = 1 to 2 parts CO_2 per 1,000.	1.8 parts per 1,000.
" " " " " "	1.858 parts per 1,000.
" " " " " "	2.319 " " "
" " " " " "	1.370 " " "
" " " " " "	1.630 " " "
Very bad = 2 to 4 parts CO_2 per 1,000.	1.750 " " "
" " " " " " " "	1.583 " " "
Pure = 0.5 to 0.7 parts CO_2 per 1,000.	0.664 " " "
" " " " " " "	0.837 " " "
" " " " " " "	0.596 " " "
" " " " " " "	0.919 " " "
" " " " " " "	1.056 " " "
Passable = 0.7 to 1.0 parts CO_2 per 1,000.	1.080 " " "
" " " " " " "	1.600 " " "
" " " " " " "	1.518 " " "

Of the "ready" or minimetric methods for the determination of carbonic acid in the air, that of Lunge-Zeckendorf recommends itself by reason of its simplicity and relative degree of accuracy. The results obtained by this method, as can be said of all "ready methods," are not absolutely exact, but they approximate sufficiently to make the method of practical utility. The best results are obtained by this method when the proportion of carbonic acid is not less than 1 part per thousand. For smaller amounts than this, analysis by this method requires too much time.

The analysis is made by the use of a solution of sodium carbonate with phenolphthalein as indicator.

The solution is: Desiccated sodium carbonate, 5.3 grams; distilled water, 1,000 c.c.

When the soda is dissolved one gram of phenolphthalein in substance is to be added. The distilled water should have been boiled and quickly cooled just before making the solution, and the solution should be kept in a tightly-stoppered bottle.

When the analysis is to be made, 2 c.c. of the above solution are to be added to 100 c.c. of boiled and cooled distilled water, and of this 10 c.c. are employed in the apparatus shown in Fig. 18. This apparatus, as the figure shows, consists of a flask of about 125 c.c. capacity provided with a rubber stopper, through which pass two glass tubes. One of these tubes passes to the bottom of the flask, the other is cut off flush with the under surface of the stopper. The tube passing to the bottom of the flask is connected by a rubber tube with a rubber bulb of 70 c.c. capacity, which serves to force the air under consideration through the test fluid in the flask. Before placing the test solution in the flask all air should be expelled from it and replaced by the air to be analyzed

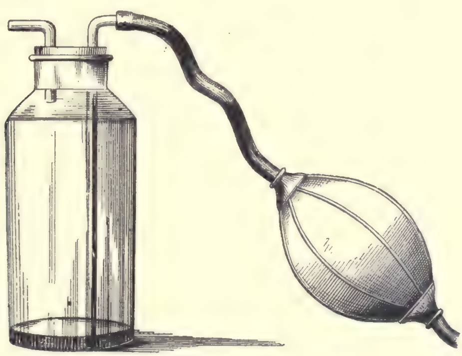

FIG. 18.

by pressing the bulb between the thumb and index finger several times. When this is done 10 c.c. of the diluted stock solution (2 c.c. to 100 c.c. of distilled water, which has been boiled and cooled) are placed in the flask, the stopper quickly replaced, and the apparatus is ready for use.

The air to be tested is then forced through the solution by pressing the bulb between the thumb and index finger once, after which the rubber tube is pressed between the fingers and the flask shaken for one minute, care being given that the fluid does not escape through the glass tubes. If no change of color occurs, the rubber bulb is refilled and pressed and in this way air is forced through the solution until the red color of the solution disappears. From the number of times the

bulb is filled and its contents forced through the fluid, the proportion of carbonic acid in the air is determined by the following table :

Disappearance	of color	with	48	compressions	of the	bulb =	0.3 CO_2	in	1,000 air.
"	"	"	35	"	"	"	0 4	"	"
"	"	"	27	"	"	"	0.5	"	"
"	"	"	21	"	"	"	0.6	"	"
"	"	"	17	"	"	"	0.7	"	"
"	"	"	13	"	"	"	0.8	"	"
"	"	"	10	"	"	"	0.9	"	"
"	"	"	9	"	"	"	1.0	"	"
"	"	"	8	"	"	"	1.2	"	"
"	"	"	7	"	"	"	1.4	"	"
"	"	"	6	"	"	"	1.5	"	"
"	"	"	5	"	"	"	1.8	"	"
"	"	"	4	"	"	"	2.1	"	"
"	"	"	3	"	"	"	2.5	"	"
"	"	"	2	"	"	"	3.0	"	"

This process has been repeated, and parallel comparisons made with Pettenkofer's method by Fuchs, who found that the very dilute solution employed by Lunge-Zeckendorf, when used for very impure air, gave irregular results, and decided from the result of his comparisons that more exact and regular results could be obtained where 4 c.c. of the stock solution, instead of 2 c.c., were added to 100 c.c. of distilled water, and this employed in the flask as test fluid. He found :

Disappearance of	color	with	16	compressions	of bulb =	1.2 Co_2	in	1,000	air.
"	"	"	8	"	"	2.0	"	"	"
"	"	"	7	"	"	2.2	"	"	"
"	"	"	6	"	"	2.5	"	"	"
"	"	"	5	"	"	3.0	"	"	"
"	"	"	4	"	"	3.6	"	"	"
"	"	"	3	"	"	4.2	"	"	"
"	"	"	2	"	"	4.9	"	"	"

As a result of a critical review and comparison of the minimetric methods in vogue for the approximate determination of the proportion of carbonic acid in the air, Bitter (Zeitschr. f. Hygiene, Bd. IX., 1890), concludes that the method of Lunge-Zeckendorf gives by far the most accurate results, and for hygienic purposes is to be recommended above all the others, not only because of its accuracy, but also because of its convenience. The result of his analyses by this method, as com-

pared with analyses of the same air by an exact modification of the Pettenkofer method, will be seen in the accompanying table.

TABLE.

Experiment.	Lunge's Method, CO_2 in 10,000 Air.	Exact Method, CO_2 in 10,000 Air.
1	5.96	6 60
2	16.00	15.50
3	13.70	13.50
4	10.56	11.15
5	9.19	9.00
6	10.56	10.00
7	17.50	21.00
8	3.65	5.10

As has been stated, these ready tests cannot be considered absolutely accurate, so that, where accuracy is desired, methods requiring acquaintance with chemical manipulations and the use of a chemical laboratory must be employed. Of these more accurate methods, the one most commonly employed is that of von Pettenkofer.

This method has for its basis the fact that if one brings air containing carbonic acid in combination with barium hydroxide in solution a combination between the barium and the carbonic acid immediately takes place, and insoluble barium carbonate is precipitated, expressed thus:

$$Ba(OH_2) + H_2CO_3 = BaCO_3 + 2H_2O.$$

If now the barium solution be of constant strength and we have some reagent by means of which this strength may be determined before and after the barium water has been exposed to the carbonic acid it is very easy to determine what amount of carbonic acid was present from the amount of barium which has been taken for the solution as insoluble carbonate.

For this purpose a solution of oxalic acid of definite strength is employed. Oxalic acid has exactly the same effect upon barium water as carbonic acid, and in solutions of proper strength will be equivalent to a definite amount of carbonic acid. One determines, therefore, the amount of oxalic acid solution necessary to exactly neutralize a given amount of the barium solution. The same amount of barium solution is now shaken with air containing carbonic acid and after the insoluble barium carbonate has settled to the bottom we again deter-

mine the amount of the oxalic acid solution necessary to saturate the remaining barium hydroxide in the clear supernatant fluid.

By subtracting the amount of oxalic acid required after the barium hydroxide solution has been exposed to the carbonic acid from that required before the exposure, it will be easy to determine from the difference the amount of carbonic acid which was present in the air under consideration.

SOLUTIONS REQUIRED.

Oxalic Acid Solution.—As stated above, if carbonic acid is brought in contact with barium water, barium carbonate is precipitated according to this formula:

$$Ba(OH_2) + H_2CO_3 = BaCO_3 + 2H_2O.$$

If now we substitute for the carbonic acid a body which has the same action upon barium hydroxide, oxalic acid for example, we shall have this reaction:

$$Ba(OH_2) + C_2H_2\,O_4 = Ba\,C_2O_4 + 2H_2O.$$

We see, therefore, that with each molecule of barium hydroxide the same chemical reaction takes place with a molecule of oxalic acid as with a molecule of carbonic acid. In other words, a molecule of oxalic acid is chemically equivalent to a molecule of carbonic acid.

Now, since the molecular weight of carbonic acid (CO_2) is 44,

$$\begin{array}{ll} C & = 12 \\ O_2 & = \underline{32} \\ & \ 44 \text{ molecular weight,} \end{array}$$

and that of oxalic acid ($C_2H_2O_4$) + $2H_2O$ is 126,

$$\begin{array}{ll} C_2 & = 24 \\ H_2 & = 4 \\ O_4 & = \underline{64} \\ & \ 92 + 2H_2O = 126 \text{ molecular weight,} \end{array}$$

the $2H_2O$ being water of crystallization, we see that by weight 126 parts of oxalic acid have the same chemical action as 44 parts of carbonic acid—that is, 126 parts by weight of the one will neutralize exactly the same amount of barium hydroxide as will 44 parts by weight of the other.

Knowing this we make a solution of oxalic acid of such strength that each cubic centimeter shall represent a definite amount of carbonic acid. This being determined we may then calculate the amount of CO_2 which was present in the air from the difference between the

amount of the oxalic acid solution necessary to neutralize a given amount of our barium water before the exposure to CO_2 and the amount needed after the exposure. For example: Suppose 25 cubic centimeters of one barium solution before exposure to the carbonic acid were exactly neutralized by 25 c.c. of an oxalic acid solution each cubic centimeter of which represented 0.25 c.c. of CO_2; after exposure to the carbonic acid only 20 c.c. of the oxalic acid solution were needed we see then that the amount of CO_2 which has combined with barium is represented by 5 c.c. (25 c.c.—20 c.c.) of our oxalic acid. As 1 c.c. of the oxalic acid is equivalent to 0.25 c.c. CO_2, 5 c.c. will equal 1.25 c.c. CO_2; in other words, 1.25 c.c. of CO_2 have combined with the barium.

A solution of oxalic acid of such strength that 1 c.c. represents exactly 0.25 c.c. of carbonic acid contains 1.405 grams oxalic acid to the litre of distilled water, as will be now shown.

We saw that 126 parts or milligrams of oxalic acid are equivalent to 44 parts or milligrams of carbonic acid; 1 milligram of carbonic acid at 0° C. measures in volume exactly 0.5084 cubic centimeters, 760 m.m. pressure, hence 44 milligrams have a volume of 22.3676 c.c. Our solution of oxalic acid is to be of such strength that 1 c.c. will be equivalent to 0.25 c.c. carbonic acid. Therefore, if 127 mgs. oxalic acid are equivalent to 22.3676 c.c. CO_2, x milligrams of oxalic will equal 0.25 c.c. CO_2 — $126 : 22.3676 = x : 0.25$ $x = 1.405$ mgs. oxalic acid.

If, therefore, we dissolve 1.405 grams of oxalic acid in a litre of distilled water, 1 c.c. of the solution will contain 1.405 mgs. and will be equivalent to 0.25 c.c. of CO_2.

In making the solution it is necessary that chemically pure crystals of oxalic acid be used; that they be dried between folds of filter paper at even temperature for several hours before weighing; that the solution be made in a measuring flask of exactly 1 litre capacity, and that the solution be kept in a black bottle with well-fitting, ground-glass stopper.

Barium Solution.—The barium solution is made by dissolving pure barium hydroxide $Ba(OH_2)$ in distilled water. It should be of such strength that 25 c.c. of it are neutralized by about 25 c.c. of the oxalic acid solution. For a solution of this strength 3.5 grams of pure barium hydroxide are dissolved in a litre of distilled water. Since the most of the samples of barium hydroxide contain small amounts of the hydroxides of the alkalies, potassium and sodium, it is well to add to each litre of the above solution 0.2 gram of barium chloride in order to remove these foreign hydroxides.

The barium solution must be kept in a flask so arranged as to prevent access of carbonic acid to it from without, otherwise its strength will be constantly diminished by the action of this gas. Such an arrangement is represented in Fig. 19.

Indication.—The solution employed to indicate the exact point at which neutralization is accomplished is either one of rosolic acid or phenolphthalein.

If the former, it is made by dissolving 0.5 gram of rosolic acid in 100 c.c. of 80 per cent. alcohol.

In an alkaline medium a few (5) drops of this solution give a distinct rose color, which instantly disappears with the least trace of acidity.

If the latter is selected, 3 grams of phenolphthalein are to be dissolved in 100 c.c. of alcohol. This solution is colorless, but in alkaline solutions becomes distinctly red in color.

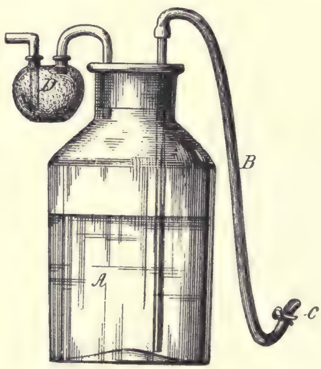

FIG. 19.

A, flask containing the barium water.
B, glass syphon for drawing off the solution.
C, rubber tube, closed by pinch cock, into which the tip of pipette may be inserted for drawing off the solution.
D, absorption bottle containing broken pumice stone saturated with strong solution of caustic soda. It robs the air passing into the flask of its carbonic acid.

Method of Performing the Analyses.—When the solutions have been prepared the exact volume of the flask in which the sample of air is to be collected must be determined. This is done as follows:

At 15° C. the weight of distilled water expressed in grams will be equal to its volume expressed in cubic centimeters. If, therefore, we

fill a large bottle, which should be of about 5 litres capacity "struck measure," with distilled water at this temperature and weigh it and then, after emptying and drying weigh it again, the difference between the two weights will express the capacity in cubic centimeters. This, when once determined, may be written upon the bottle and thus obviate the necessity of repeating this part of the operation when the same bottle is used in further analyses. For example: Flask filled with distilled water at 15° C., weighs 6,520 grams; flask empty and perfectly dry, 1,020 grams; contents of flask at 15° C., weigh = 5,500 grams, or are equivalent to 5,500 c.c. When this is determined the sample of air may be collected in the flask.

For this the flask is closed with a rubber cap (not a stopper) and placed at the point at which the collection is to be made, where it remains for 20 to 30 minutes, until it has taken on the temperature of the air. The temperature of the air we find to be 20° C. The barometric pressure, reduced to 0° C is 720 m.m. The volume of air contained in our flask under this temperature and pressure will be found to be less than 5,500 c.c.m. when reduced to normal conditions of 0° C and 760 m.m. pressure. This reduction to normal conditions of temperature and pressure is necessary because the volume of CO_2, which will be calculated from our analysis of the barium water, is expressed in these terms, and the conditions in both cases must be alike in order to compare them.

Another correction to be made in the volume of our flask is for the 100 c.c.m. of barium water, which must be employed to absorb the CO_2 in the sample of air which will be collected in the flask. This 100 c.c. must therefore be subtracted. We have then, 5,500 − 100 = 5,400 c.c.m., as the volume of our flask under the observed conditions of 20° C. temperature and 720 m.m. barometric pressure.

Reducing then by aid of the formula given in the chapter on physical properties of the air, we have

$$V = \frac{v \cdot p}{760\ (1 + (0.00366 \times t^\circ)}$$

substituting the figures

$$V = \frac{5{,}400 \times 720}{760\ (1 + (0.00366 \times 20)} = 4{,}766.6 \text{ c.c.m.}$$

Under normal conditions, then, the volume of air contained in the air flask measures 4,766.6 c.c.m.

The cap is now removed from the flask and all the air is expelled from the bottle, and is substituted by the air to be analyzed by from 50 to 75 compressions of an average size bellows. To the nozzle of the bellows a rubber tube must be attached in order that the air may be introduced at the bottom of the flask.

The cap is now replaced and by means of an accurate pipette of 100 c.c.m. capacity this amount of barium water is introduced into the flask by gently raising one corner of the rubber cap and inserting the nozzle of the pipette as deep down into the flask as possible. After very gently agitating the flask, being careful that the barium water does not touch the rubber cap, for 20 minutes, all the CO_2 in the air in the flask will have been absorbed by the barium. The 100 c.c. of barium water is now poured off through a funnel into a smaller bottle of about 125 c.c. capacity, which is to be tightly closed with a ground-glass stopper, and allowed to stand for about three hours, after which time all the barium carbonate shall have settled to the bottom, and the supernatant fluid will be quite clear. In the mean time we determine exactly the relation between our stock barium water and our standard oxalic acid solution. For this purpose exactly 25 c.c.m. of the barium solution is pipetted off from the flask containing the supply stock into a 100 c.c. Florence flask, and to this five drops of our indicator solution is added. If the rosolic acid solution is employed the whole takes on a distinct rose color. We now allow the oxalic acid to flow into the flask from an accurate burette, and note carefully the exact instant at which the rose color disappears. By making two of these determinations and taking the mean of them, providing they do not differ more than 0.2 c.c. the one from the other, we get the exact amount of the oxalic acid necessary to neutralize 25 c.c. of our barium solution *before* exposure to the CO_2.

From the small bottle containing the 100 c.c. of barium water which has been exposed to the CO_2, two samples of 25 c.c. each are now taken and treated in exactly the same way. It will be found that less of the oxalic solution will be required than was needed to neutralize the same amount of the barium water before its exposure to the CO_2. Some of the barium has therefore been thrown down as insoluble carbonate. Now, since our oxalic acid solution is so made that each cubic centimeter represents a definite volume of CO_2, it is easy to calculate the amount of CO_2 which has combined with the barium in the 100 c.c. of barium water by multiplying the difference between the two titrations by 0.25, which is the value of each cubic centimeter of our oxalic acid expressed in terms of carbonic acid by volume, and

this by 4 to find the amount for the whole 100 c.c., since only one-quarter of the whole amount was employed in the titration.

Example:—

25 c.c. barium water before exposure to CO_2	= 24.8 c.c. oxalic acid.
25 c.c. " " after " " "	= 23.3 c.c. " "
Difference for 25 c.c.	= 1.5 c.c. " "
Difference for 100 c.c.	= 6.0 c.c. " "

One cubic centimeter of our oxalic acid solution is equivalent to 0.25 c.c. carbonic acid, therefore 6.0 c.c. will equal $0.25 \times 6 = 1.5$ c.c. carbonic acid at 0° C. and 760 m.m. pressure, which was present in 4,766.6 c.c.m. air under the same conditions.

The relative amount of carbonic acid present in air is for convenience expressed in parts in 10,000, hence

$$4{,}766.6 : 1.5 = 10{,}000 : x.$$

$x = \dfrac{1.5 \times 10{,}000}{4{,}766.6} = 3.15$ parts of CO_2 in 10,000 parts of the air analyzed.

This is the method commonly employed for accurate carbonic acid analyses. It requires, however, some acquaintance with chemical methods of manipulation, and to those who are unpracticed in such work a few weeks' instruction in a properly equipped laboratory is recommended.

Apparatus and solutions required for Pettenkofer's CO_2 method: To summarize the apparatus and solutions required for this analysis :

(1) About 4 litres of barium solution in such a flask as is shown in Fig. 76. Strength of solution $= \begin{cases} \text{barium hydroxide, 3.5 grams ;} \\ \text{barium chloride, 0.2 grams ;} \\ \text{dist. water, 1,000 c.c.} \end{cases}$

(2) Oxalic acid solution, containing 1.405 grams of chemically pure oxalic acid crystals to the litre.

(3) Rosolic acid solution, 0.5 grams rosolic acid to 100 c.c. of 80 per cent. alcohol.

(4) One 100 c.c. pipette, with long nozzle.

(5) One 25 c.c. pipette.

(6) One 50 c.c. burette, divided into 0.1 c.c.

(7) One bellows, with rubber tube about 2 feet long attached to nozzle.

(8) One large flask of about 5 litres capacity with well fitting rubber cap.

(9) One small bottle of about 125 c.c. capacity, the stopper to be of glass and well fitting.

(10) Two 100 c.c. Florence or Ehrlenmeyer flasks.

(11) One small funnel.

(12) One accurate centigrade thermometer.

(13) A barometer.

The alterations in volume expressed by such a small volume of air, as we supply, through variations in barometric pressure, are so slight that this factor may be omitted where the rise and fall of the mercurial column does not exceed 10 m.m. above or below the normal point (760 m.m.)

In collecting the air to be analyzed, care must be had that a fair sample is obtained. That is, there should be no one around the immediate neighborhood of the bellows other than the manipulator, and he, too, should take care that none of his own expired air is pumped directly into the flask.

Where it is desirable to have the analysis extend over a longer period of time, for the purpose of determining the mean proportion of CO_2 in the air during this time, or where the air to be analyzed is in such a place that one cannot conveniently use the method above described, Pettenkofer recommends the aspiration of the air through baryta water contained in tubes of the form seen in Fig. 20. The same solutions are employed, and the method of calculating the results is the same, the only difference being that instead of collecting the sample of air in a flask and exposing it to baryta water in this flask, it is drawn through the baryta water in a tube. This method finds application in the study of ground air, the air of wells and the air of closed spaces with small openings.

In this method the tubes are arranged as shown in Fig. 20. and the air is aspirated through them in a slow stream so that it passes through the solution in single bubbles. Usually all carbonic acid is absorbed in the first tube, but to prevent error the second tube is added in order to check any of the gas that might have passed the first tube unabsorbed.

In practice the air analyzed by this method is commonly supposed to be richer in CO_2 than the free atmosphere, so that a stronger baryta solution (10 grams $BaOH_2$ and 0.4 gram $BaCl_2$ to the litre) is employed; likewise the oxalic acid solution may be made so that each cubic centimeter will be equivalent to 0.5 c.c. of carbonic acid (2.810 grams oxalic acid to 1,000 c.c. water). After the desired amount of air has been slowly aspirated through the solution the tubes are quickly emptied into bottles in exactly the same way as when the flask method is em-

ployed, and after standing for three or four hours the supernatant clear portion of the solution is pipetted off and titrated with the oxalic acid solution. The difference between the titration of the baryta water before and after the passage of the air through it, expressed in cubic centimeters of oxalic acid, is easily converted into terms of carbonic acid (1 c.c. oxalic acid of the stronger solution = 0.5 c.c. carbonic acid) and from this may readily be calculated the proportion of carbonic acid per 10,000 parts air by the proportion:

a parts air aspirated : b parts CO_2 absorbed = 10,000 air : x CO_2.

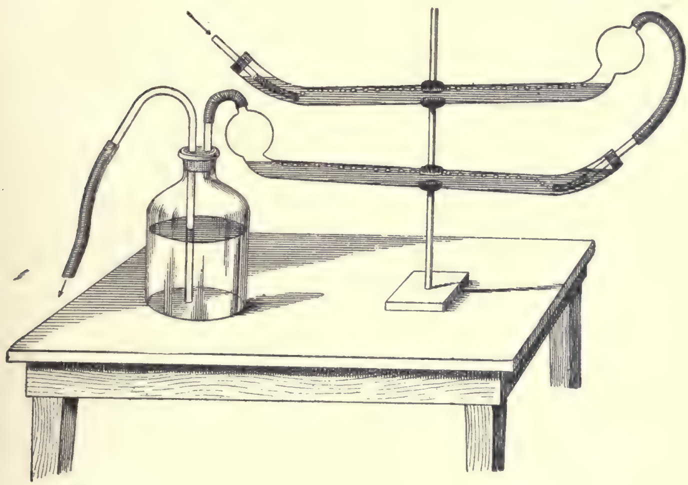

FIG. 20.

In regard to the estimation of carbonic acid in the air by the barium method, Smith (Veterinary Journal and Annals of Comparative Pathology, 1886, Vol. 22, p. 85,) makes the following observations: If ammonia is present in any appreciable amount, the results of the carbonic acid analyses by baryta water are unreliable if made close to the ground. The ammonia affects the sensitiveness of the baryta solution to which the air is exposed, and makes it appear to be purer than it really is. To avoid this fallacy, air must be collected from at least 6 feet above the ground.

Another method for the estimation of this gas in the air, which is said to be reliable and easy of performance, is that of Szydlowski (St.

Petersburger Medicinische Wochenschrift, 1880, No. 23). It is as follows :

The apparatus consists of two thick-walled glass vessels *A* and *B*, which communicate the one with the other through the thick-walled glass tube *C*, which has a caliber of 1 m.m. diameter.

The capacity of the vessel *A* from the mark *m* to the mark *n* is exactly 100 c.c. at 17½° C.

The vessel *B* must be larger than *A*. Its exact capacity is not important.

On the upper end of the vessel *A* is a horizontal glass tube with two tightly-fitting cocks, *p* and *q*.

The left extremity of this tube with the cock *p* is connected by a closely-fitting rubber tube with the U-tube *D*, which contains bits of

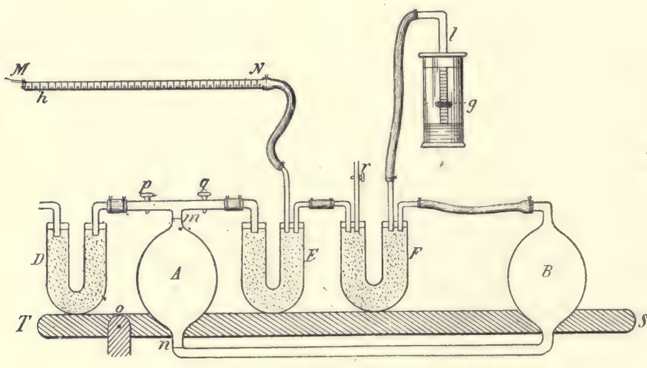

FIG. 21.—SZYDLOWSKI'S METHOD.

pumice stone which have been soaked in concentrated H_2SO_4. The tube *D* is for the purpose of drying the air to be analyzed and is known therefore as the "drying tube."

The right extremity of the horizontal tube with the cock *q* is connected with the U-tube *E*, both arms of which are filled with granular soda-lime, over the top of which should be placed a wad of cotton or asbestos, which will prevent the dust from the soda-lime being carried along in the air current.

In the right arm of the tube *E* are two glass tubes, the one of which is to be connected with the horizontal pipette *MN*, which is to be divided into $\frac{1}{1000}$ c.c.

The other tube connects with the left arm of U-tube *F*, which arm is also filled with granular soda-lime. From the left arm of tube *F* is also a second vertical tube with glass cock *v*.

The right arm of the tube *F* is filled with granular calcium chloride. From the right arm of tube *F* pass two glass tubes, the one of which connects with the capillary tube *l*, the other with the vessel *B*.

Both arms of tube *E* and the left arm of tube *F* absorb the carbonic acid of the air under investigation.

The right arm of tube *F* takes up the water-vapor which should be formed when the CO_2 is taken up by the soda-lime.

The tubes *E* and *F* are the absorption apparatus.

The whole of the apparatus, except the capillary pipette *MN* and the capillary tube *l*, is made fast to the board *TS*. At the point *o* the board is swung on a pivot which permits its motion in the direction indicated by the arrows at *S*.

The vessel *B* is to be filled with pure dry mercury, so that if the end *S* of the board be lowered, all the mercury will flow out of the vessel *A*, through the tube *C* into *B*, and the space from *M* to *N* (100 c.c.), will contain nothing but air.

If the end *S* of the board be raised, a reverse current of mercury is started and *A* will be filled and *B* empted.

When the mercury has filled *A*, exactly up to the mark *M*, the apparatus is fixed in position.

In the capillary pipette *MN* is a short mercurial column *h*.

On the end *M* is a short rubber tube, which upon being pressed between the fingers, serves to regulate the position of the mercurial column *h*.

The capillary tube *l* is divided exactly into division of 1 m.m. apart. It is allowed to hang vertically through a cork (not air-tight), in the vessel *g* which contains a colored, dilute caustic soda solution. The capillary tube is immersed in the soda solution, so that its first division corresponds with the normal meniscus. Through capillarity the fluid ascends in the capillary tube. The exact point to which it ascends is marked by a bit of paper pasted upon the outside of the vessel *g*. By this arrangement the ascent of the fluid in the tube *l*, when the carbon is absorbed from the air being analyzed can always be determined with exactness.

All joints of the apparatus must be made air-tight by the use of an alcoholic solution of sealing-wax or lac.

If from any volume of dried air enclosed in an air-tight space the carbonic acid be removed there results a diminution in the pressure.

If the pressure is to be kept constant then must the volume be reduced by exactly the same amount as the volume of the carbonic acid which has been removed.

If the end *S* of the board be lowered until the mercury fills the vessel *B* and the tube *C* up to the mark *n*, and the cocks *p* and *v* be closed then all parts of the apparatus are filled with air, except the vessel *B* and the tube *C*. If now the end *S* of the board be raised then the mercury flows through *C* into *A* and drives the air from *A* before it through the absorption apparatus, where it leaves its carbonic acid, into *B*. Lower the end *S* of the board and the mercury returns to *B* and the air to *A*.

By repeating this several times the air in *A* eventually is free from carbonic acid. This must be done as a preliminary cleansing of the apparatus whenever new materials are employed and a fresh analysis is to be made.

After thus cleansing the apparatus, before taking the sample, the end *S* of the board is to be raised until the vessel *A* is filled with mercury exactly to the mark *m*. The cock *q* is now to be closed and the cocks *p* and *v* are to be opened. The end *S* of the board is now to be lowered until all the mercury flows out of *A* into *B* and fills *B* and the tube *C* exactly up to the mark *n*. The vessel *A*, which from *m* to *n* has a capacity of exactly 100 c.c., will now be filled with the air to be analyzed instead of mercury. This air is dried in the tube *D*, through which it must pass in reaching *A*. The air which was in *B* escapes through the tube with the cock *v*. One must now bring the mercurial column in the pipette *MN* exactly on the first division at the end *M*, record the exact height of the colored solution in the capillary tube *l*, close the cocks *p* and *v* and open *q*, and raise the end *S* of the board. The air to be analyzed will now be driven from the vessel *A* through the absorption apparatus over into the vessel *B*. Its CO_2 will be taken up in the absorption tubes, and in consequence its volume will be diminished by an amount equivalent to the volume of the CO_2 thus absorbed. As the air is in a closed vessel, and its volume has been diminished, its pressure will therefore be reduced, as may be seen by a rise of the colored fluid in the capillary tube *l*. This rise of fluid compensates for the diminution in volume of the air in the apparatus—in other words, lessens the volume of the apparatus itself. To make this lessening in volume of the apparatus fixed, before driving the air over the absorption apparatus a second time—for all the CO_2 may not have been absorbed in the first excursion through *E* and *F*—the mercurial column in the pipette *MN* is moved along toward *N* until the colored

fluid in the tube l returns to the normal level, as indicated by the upper edge of the paper g.

The air may now be driven from A again through the absorption apparatus, and if no rise of the fluid in l occurs, then all the CO_2 has been absorbed.

One reads now the exact number of divisions on the pipette MN; it was necessary to move the mercurial column h, in order to bring the fluid in l to its normal level. The result is the volume of carbonic acid which was contained in ·100 c.c. of air—*i. e.*, the per cent. of CO_2 present.

The mercury may now be allowed to flow back into A up to m, and the apparatus is ready for a second analysis.

Precautions.—In order that the results may be exact, it is desirable to prevent any elevation in the temperature of the air in the apparatus over that of the surrounding air. It is therefore to be recommended that the observer avoid as much as possible the handling of the glass parts, and that he should stand as far from the apparatus as convenient.

If these precautions are not observed, the air in the apparatus will be expanded, by reason of its elevation in temperature, and the result will be too small a relative proportion of CO_2.

The readings must be made from as great a distance from the apparatus and with as much rapidity as is consistent with accuracy.

In passing through the tube D, the temperature of the air is elevated by the heat generated when the H_2SO_4 takes up the water-vapor. It is necessary, therefore, to wait at least five minutes before the cock p is closed and the experiment begun.

One should not hasten to regulate the level of the column of fluid in the tube l, nor the position of the mercurial column in the pipette MN.

One should wait a minute before moving the mercurial column h. It should then be moved slowly and regularly.

By following the above directions, Szydlowski claims that an analysis should not take over 20 minutes.

The time may be shortened by placing the whole apparatus, except the two capillary tubes MN and l, in a large vessel of water of the same temperature as the air of the room.

The whole apparatus should not be larger than 40 c.m., nor wider than 15 c m., nor higher than 30 c.m.

Reiset (Comptes Rendus, Tome 90, 1880, p. 1,145; Ann. d. Chim. e. d. Phys., Tome 26, 1882, p. 164) describes the following apparatus

as a convenient means of determining the proportion of CO_2 in the atmosphere.

The apparatus (Fig. 22) consists of a flask *F* of about 500 c.c. capacity. This flask has two openings, one at *J* through which the tube *T* passes, and the other at *t'* through which tube *t* passes.

The tube *T* is about 50 c.m. over all, and has an inside diameter of about 40 m.m. At the points *c*, *c'* and *c''* in this tube are three platinum disks which fit in the tube snugly. They are each perforated by 25 holes of 0.5 m.m. in diameter.

Tubes *I* and *II* are filled with pumice stone saturated and corked in concentrated H_2SO_4—at the bottom of each of these tubes is a bulb for the reception of the acid as it becomes diluted and increased in volume by the addition of water-vapor—this prevents the capillary pores and spaces between the bits of pumice stone from becoming clogged and thus prevent the free passage of air.

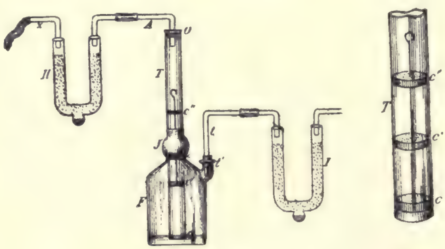

FIG. 22.

The tube *T* is introduced into the flask *F*, as shown in drawing, and the joint between it and the flask made air-tight by means of rubber tubing, as shown at *J*.

At *t'* another tube of much smaller diameter, *t*, is introduced through a tightly-fitting rubber cork.

The drying tube *I* is now placed in position. This drives the air before it passes into *F*.

The tube *II* is for the determination of the amount of water which has evaporated from the barium solution, which is to be placed in *F*, during the experiment.

Three hundred c.c. of barium water are placed in *F* through the opening *O*, the stopper at *O* replaced and the end *x* connected with an aspirator. A measured volume of air is drawn through the baryta water. After a sufficient amount has passed the apparatus is disconnected from the aspirator, and the baryta water titrated.

From the difference between the titration of the water before and after passage of the air the amount of CO_2 is calculated.

A method of examining the atmosphere in mines that is now being used at Kolscheid near Wachen, and which is said to prove useful and reliable, is as follows: A collecting gasometer is placed in the chief ventilating shaft. It is so arranged that it becomes filled in 12 hours; in this way it is possible to obtain a fair average sample of the mine air. From the air thus collected the free carbonic acid is absorbed by caustic soda and its percentage by volume is estimated by noting the diminution in bulk. The marsh gas, which is the dangerous element in the atmosphere of the pit—the so-called fire damp of the miners—is now decomposed by a platinum wire heated to incandescence by means of an electric current. A further diminution in bulk takes place, and this being observed, the percentage of marsh gas present can be calculated.

It is advisable for all architects to familiarize themselves with the ready methods for the approximate estimation of carbonic acid in the air and to appreciate the importance of more exact analyses when the results of the ready tests suggest it, for it is only in this manner that they can prove that their buildings are properly ventilated, or can decide positively on the merits of the dozens of patent ventilating appliances, which are fast becoming as much of a nuisance as patent lightning rods.

It is true that by measuring carefully the quantity of air entering a room in a given time, and taking this result in connection with the position of registers, etc., a person of experience can form a very accurate and reliable opinion as to the character of the ventilation of the room; but as explained above, the phrase, "good ventilation," implies a thorough mixing of the foul air with that which is pure, and the chemical test is the only one which will show whether this mixing has been effected or not.

In this connection attention should be called to a property of air, which is important in ventilation problems, although it is hardly alluded to in books, and that is its tendency to adhesion to surfaces, even when in motion.

The best mode of illustrating it is, perhaps, an experiment devised by the late Prof. Joseph Henry. Upon a large, smooth table, sprinkle uniformly some light powder, such as powdered lycopodium. In the middle of the table place a bell glass, mouth downward. Then with a pair of bellows direct the current of air from the edge of the table toward the center of the bell glass. The track of this current

will be distinctly marked in the powder, and when it reaches the bell glass you will see it divide into two parts, one passing on one side, the other on the other, but both adhering to the glass until they meet on the opposite side, when then they will join and continue in their original direction.

When a current of air is started along a wall or floor, it may adhere to it for several feet, or even yards, and in this way we may have annoying draughts at points where we had least expected them.

In the Hall of the House of Representatives, at Washington, a few years ago, a large part of the fresh air was brought in through the risers of the platforms upon which the chairs of the members are placed. This sheet of air, introduced under pressure, and in a horizontal direction, did not diffuse directly upward, as it was intended to do, but adhered to the floor, and swept across the ankles of the member just in front. When it had passed his desk and reached the next riser, it was reinforced by a fresh stratum, and the honorable member next in front received the upper current on the calves of his honorable legs, while the floor current swept his ankles, to his great discomfort and dissatisfaction.

In like manner the current from a warm-air register, placed in the floor in the corner of a room, adheres to the sides of the room and passes directly upward, almost as if it were in a tube. It then streams along the ceiling to an opening into a foul-air flue in the opposite corner, and passes out without disturbing the air in the lower part of the room.

In this way it may happen that a sufficient quantity of air may be passing into and out of a room and yet that the ventilation may be extremely unsatisfactory. It is necessary to secure distribution as well as entrance and exit.

For the determination of organic matter in the air, Carnelley and Mackie* propose the following method as a substitute for the two methods of Smith hitherto employed—viz.: the passage of a measured volume of air through potassium permanganate solution of known strength, after which the loss experienced by the permanganate solution, expressed in volumes of oxygen necessary to oxidize the organic matter in the air passed through it, is determined by titration; or the passage of air through distilled water, the amount of albuminoid thus added to

* Carnelley and Mackie, "The Determination of Organic Matter in the Air," Proc. Roy. Soc., London, 1886, No. 41, p. 238.

the water being determined by the method suggested by Wanklyn and Chapman for water analysis.

Both ot these methods require much time, considerable apparatus, and are, according to Carnelley and Mackie, open to errors of greater or less extent, depending upon circumstances.

The method proposed is based upon the reduction of potassium permanganate. It differs, however, from Smith's method, particularly in the mode of determining the amount of reduction. This consists in determining, *calorimetrically*, by comparison with a standard, the fractional bleaching effected by a known volume of air.

Method.—The solution of permanganate employed is of $\frac{n}{1,000}$ $\left(\frac{1}{1,000}\text{ normal}\right)$ strength, 1 c.c. of which = 0.008 mg. of oxygen, the volume of which is, under normal conditions, 0.0000056 litre.

It is usually kept of $\frac{n}{10}$ strength, and diluted as required for use, about 50 c.c of dilute sulphuric acid (1.6) being added to the weak solution.

For the collection of samples of air large, well-stoppered bottles of about 3.5 litres capacity are used. The jars are first rinsed out with a little standard permanganate, and when not in use a little of the solution is always left in them, so as to insure complete freedom from any reducing substance. Before use the jars are drained, and the sample of air is then collected by pumping out the contained air with a small bellows and allowing the air to be analyzed to flow in; 50 c.c. of the standard permanganate are next run into the jar, which is then tightly stoppered and well shaken for at least five minutes; 25 c.c. of the permanganate are afterwards withdrawn by a pipette and placed in a glass cylinder holding about 200 c.c., 25 c.c. of the standard solution being placed in a similar cylinder for comparison. Both are now diluted up to about 150 c.c. with distilled water, and allowed to stand for 10 minutes, after which the tints in the two cylinders are compared. Standard solution is then run from a burette into the cylinder containing the solution, which has been acted upon by the air under examination until the solutions in the two cylinders are of the same intensity of color; usually from 0.5 to 6. c.c. are required.

The amount of solution added from the burette is a measure for the bleaching effected by the known volume of air in the flask on half

the permanganate employed. This multiplied by 2 gives the total bleaching.

The result may be expressed either in terms of the number of c.c. of the $\frac{n}{1,000}$ bleached by 1. litre of air, or, as is preferred, by the number of volumes of oxygen required to oxidize the organic matter in 1,000,000 volumes of air; *e. g.*, 25 c.c. of a solution from a 3.5-litre jar in which 50 c.c. had been used, required 3 c.c. of the permanganate to bring it up to the standard, or the whole 50 c.c. would have required $3 \times 2 = 6$. c.c. This, then, represents the number of c.c. of the standard solution bleached by $3,500 - 50 = 3,450$ c.c. of air; consequently $\frac{6}{3.45} = 1.74$ c.c. is bleached by 1 litre of air. But 1. c.c. of $KMnO_4 =$ 0.0000056 litre of oxygen $\therefore$ 1.74 c.c., $KMnO_4 = 0.0000056 \times 1.74 =$ 0.0000097 litre of oxygen is required to oxidize the organic matter in 1 litre of air, or 9.7 volumes of oxygen to oxidize the organic matter in 1,000,000 volumes of air.

Correction for temperature is not considered necessary, as it falls within the limits of experimental error. It requires about 20 minutes to collect the sample and complete the analysis. Scrupulous cleanliness is, of course, necessary in all the operations.

After the examination of many hundreds of samples of air by this process Carnelley and Mackie are led to believe that the results obtained by it are as accurate as possible in the present state of our knowledge upon the subject.

Duplicate analyses of the same air gave very concordant results.

The objections to the method are:

(1) That it does not directly estimate the organic matter, but only measures the amount of oxygen required to oxidize either the whole, or, more probably, only a portion of it.

(2) That the permanganate acts upon various matters in the air besides the organic matter. such as sulphuretted hydrogen, nitrous acid, sulphurous acid, etc.

(3) That the organic matter in the air is of various kinds, and that, consequently, the permanganate will most probably be selective in its action. Our knowledge on this point, however, is so defective that no definite conclusion is possible in regard to it.

(4) There is no satisfactory means of checking the results, the only method being to make duplicate determinations of the same air.

(5) The uncertainty that the permanganate exerts its full action in a cold acid solution of such dilution as that recommended above.

This test, such as it is, the method stands extremely well, as will be seen from the results given below:

ORGANIC MATTER.

	Vols. of O Required to Oxidize the Organic Matter in 1,000.000 Vols. of Air. First Determination.	Second Determination.	Mean.	
Outside air (Dundee)..	9.0	8.9	8.95	Immediately after rain.
" " "	12.0	11.5	11.75	No rain during day.
" " "	10.0	10.2	10.10	Heavy rain with wind.
" " "	8.6	8.1	8.35	Rain shortly before.
" " (Perth)....	2.0	1.6	1.80	Strong wind and rain.
" " "	2.0	1.5	1.75	Strong wind, rain at intervals.
" " "	4.0	2.0	2.20	Storm shortly before.
" " "	4.8	4.6	4.70	Fine.
Class-room (Dundee)..	10.5	8.8	9.65	Unoccupied. Just after dusting.
" " (Perth)...	7.6	7.8	7.70	29 present for 1 hour.
" " "	4.0	5.0	4.50	31 " "
Small room...........	11.9	11.4	11.65	Unoccupied. Two gas jets burning 15 minutes.
" "	12.9	13.0	12.95	One person and 1 gas jet 20 minutes.
" "	17.2	17.0	17.10	Ditto, after 1 hour and 40 minutes.
" "	20.0	20.5	20.25	Ditto, on another occasion.

The method does not give absolute, but only relative results.

The conclusions drawn by Carnelley and Mackie as a result of their air analyses, were:

(1) That the quantity of organic matter in the outside air varies considerably, within certain limits, from day to day, and from hour to hour on the same day.

It has been found to be somewhat less immediately after or during rain or snow, thus:

	No Rain or Snow. No. of Cases.	Lowest.	Highest.	Mean.
Organic matter (O required per 1,000,000 vols. of air)........................	19	1.6	15.8	7.9
Carbonic acid (per 10,000 vols. of air)......	15	2.2	5.4	3.86

	Just after or during Rain or Snow.			
	No. of Cases.	Lowest.	Highest.	Mean.
Organic matter (O required per 1,000,000 vols. of air)	19	1.8	13.3	7.3
Carbonic acid (per 10,000 vols. of air)	11	2.4	5.6	3.95

The highest results of all were obtained on foggy nights—*e. g.*, 15.7, 17.0. High results were also obtained during a slight drizzling rain, accompanied by mist.

(2) A close connection is observed between the amount of organic matter in the air and the combustion of coal. It is lowest in the middle of the night, rather higher in the morning, and considerably higher in the middle of the day, and higher still toward evening, after which it decreases. Thus:

	Means.			
	8 P. M.—5 A. M.	5 A. M.—10 A. M.	10 A. M.—3 P. M.	3 P. M.—8 P. M.
Organic matter (O required per 1,000,000 vols. of air)	3.9	4.9	7.9	9.1
Carbonic acid per 10,000 vols. of air	4.1	2.9	3.4	3.5

(3) A relation of organic matter to carbonic acid in outside air shows, so far as the tabulated results go, a high carbonic acid accompanied by a high organic matter, and *vice versa*. This is, however, by no means invariable, and is, in fact, only shown by the averages of a large number of cases. To show this, all the determinations which have been made in the outside air were divided into four groups, according to the quantity of organic matter present and the averages of the corresponding carbonic acid found, as in the following table:

Vols. of O Required to Oxidize the Organic Matter in 1,000,000 Vols. of Air.	Average Carbonic Acid in 10,000 Vols. of Air.	Number of Determinations.
0 to 2.5	2.8	20
2.5 to 4.5	3.0	20
4.5 to 7.0	3.2	20
7.0 to 15.8	3.7	20

(4) The organic matter in the outside air has a far wider range of variations than the carbonic acid. The latter seldom passes beyond the limits of 2 to 6 volumes in 10,000, whereas the organic matter may vary from amounts too small to estimate up to that requiring as much as 16 volumes of oxygen per 1,000,000 volumes of air for its oxidation.

Its fluctuations are also more rapid.

(5) The combustion of gas does not appreciably increase the amount of organic matter in the air.

EXPERIMENTS IN A ROOM. PRACTICALLY AIR-TIGHT.

	CO_2 per 10,000 Vols. of Air.	Organic Matter (Vols. of C Required per 1,000,000 Vols. of Air.)	
Before gas was burnt......	4.3	10.6	Each of these is the mean of two nearly concordant experiments.
After gas had been burning 15 minutes.........	11.0	11.8	
After gas had been burning 30 minutes.........	14.8	11.8	

The combustion of gas may therefore be considered to have been too perfect to produce any appreciable effect. What result is obtained may safely be attributed to sulphurous acid (SO_2).

The above applies to Dundee gas, which is considered exceptionally free from sulphur.

(6) The effect of burning oil lamps is much more marked than that of the combustion of gas.

This was determined in the same manner as were the results in the case of gas—in a practically air-tight room.

RESULT OF BURNING OIL LAMPS IN A PRACTICALLY AIR-TIGHT ROOM.

	Organic Matter (O Required per 1,000,000 Vols. of Air.)	
Before the burning of oil lamps...	8.7	Each of these is the mean of two nearly concordant determinations.
After one lamp had been burning half an hour it was found to be smoking slightly.	12.3	
After burning one hour—lamp burning clear...	14.6	
After the first lamp had been burning one and one-half hour, and a second lamp half an hour, the second lamp was found smoking slightly.	16.7	
Ditto, after first lamp had been burning two hours, and the second one hour, both lamps found burning clear.	18.1	

In each case the lamps were burning paraffine oil and were turned on as full as possible without smoking.

(7) Respired air gives a higher result than unrespired air at the same time, though much less than was anticipated.

Experiments in a small, air-tight room occupied by one person. The person made the experiments in the room without opening the door. During the whole time a single gas jet was burning:

		Outside Air.	After 20 Minutes.	After 30 Minutes.	After 60 Minutes.	After 100 Minutes.
1st experiment,	CO_2.	3.8	11.4	14.8	...	....
	O.M.	9.5	12.9	14.8	....	....
2d experiment,	CO_2.	....	....	13.1	23.5	28.2
	O.M.	....	....	14.2	15.9	17.0
3d experiment,	CO_2.	....	....	17.2	24.1	32.1
	O.M.	...	....	13.5	15.7	20.3

Here it is seen that the increase of organic matter is not proportionate to the time; neither does it increase with the same rapidity as the carbonic acid.

(8) An atmosphere which has been entirely at rest for some time is found to contain less organic matter than it previously did. This is not of necessity due to the settling down of dust, but is probably due in part to oxidation.

The amount of carbonic acid is no certain index of the quantity of organic matter present in an atmosphere. That air in which respiration has gone on for some time gives invariably a higher result than outside air at or about the same time is all that can be confidently affirmed. The statement that organic matter in respired air increases *pari passu* with the carbonic acid may be true for an average of a large number of observations, but it is not true for individual cases.

Ammonia in the Air.—The presence of ammonia in the air can sometimes be demonstrated by the change in color that it produces upon delicate litmus or curcuma paper, by virtue of its alkaline reaction. A strip of moistened litmus or curcuma paper is clamped between two perfectly clean glass plates, in such a way that about one-half of it projects beyond the borders of the glasses. If ammonia is present in unusual amounts, the exposed end of the papers will be altered in color, from red to blue in the case of litmus, from yellow to brown in the case of curcuma. The bit of paper between the glass

plates is not exposed to the action of the ammonia, so that it serves as a standard with which to compare the extent of color change, which will be more rapid and greater in degree, as the amount of ammonia present is greater.

A similar test can be made with logwood paper. Bits of paper are saturated in a tincture of logwood, and exposed in the way just described. If ammonia is present, the yellow color of the paper takes on a violet or reddish violet color.

For the quantitative analyses of the air for ammonia, experience in chemical manipulation is necessary, as the greatest care is to be taken in order to exclude sources of error.

A method commonly employed for this purpose is the aspiration of a given volume of air through a given volume of a solution of sulphuric acid of known strength. The loss experienced by the acid solution, in combining with the ammonia in the air, is determined by titration, and the amount of ammonia corresponding to the amount of loss in the acid solution, is found by calculation.

Another method, that devised by Remsen, which is perhaps the most reliable of any of the methods employed for this determination, is the absorption of the ammonia from air by aspiration through a layer of pumice stone, broken into bits of about the size of a duck shot. When the desired amount of air has been drawn through the absorber (the pumice stone), the latter is then mixed with a known volume of distilled water, *free from ammonia*. By distillation, at first of the mixture as it now is with a small proportion of sodium carbonate, all ammonia, as such, is distilled over with the water, and its amount determined in the distillate by nesslerization. After this, by means of an alkaline potassium permanganate solution, the remaining organic combination, an albuminoid ammonia, as it is called, is decomposed and distilled over, and its amount determined in the same way.

These are processes that must be practiced in order that they may be properly conducted, as there are few analyses requiring greater care in manipulation than those designed for the estimation of ammonia in the air.

For the estimation of the number of micro-organisms contained in a given volume of air, quite a variety of methods exist. The simple demonstration of their presence in air without regard to relative numbers is a simple matter, requiring little or no skill on the part of the operator. A slice of freshly-cooked potato, a bit of moistened bread, or a small portion of melted gelatine, poured upon a plate, if exposed for a time to the air of an inhabited room, will be marked

after 24 to 36 hours by colonies developing from bacteria that have fallen upon it from the air. For the quantitative estimation, however, the conditions must be more carefully controlled. A measured volume of air must be aspirated over or through some medium that not only arrests the bacteria that were contained in it, but presents conditions that will permit of these bacteria being cultivated in such a way that each single bacterium will serve as a starter from which a colony will grow, and by counting these colonies, it is then easy to say how many individual organisms were present in the amount of air employed. This, in short, is the principle upon which all of these methods are based, but it must be borne in mind in making these estimations that there is one condition that it is difficult, if not impossible, to eliminate, and that is the condition in which bacteria are usually found to exist in the air. As commonly found they are located upon floating dust particles, and may be at times alone upon a bit of dust, but, as is usually the case, they are deposited upon it in numbers. It is evident, therefore, that in counting the resulting colonies as representing in each case the outgrowth from a single germ, there is always the possibility of error.

The methods commonly employed for this determination which are believed to give the most reliable results are those of Petri and its modification by Sedgwick. The former consists in aspirating the air through fine sand, which deprives it of all bacteria. When the desired amount of air has been drawn through the sand filter, the sand is mixed with sterilized fluid gelatine, which is then to be poured out upon a broad glass plate into a very thin layer. As it solidifies, each bacterium is fixed in its place in the gelatine, and proceeds to develop into a colony of bacteria. At the end of 24 to 36 hours these colonies are counted and as each is assumed to result from the growth of a single bacterium this number is assumed to represent the number of bacteria in the amount of air drawn through the sand. In the method of Sedgwick, sugar is substituted for sand, because of the insolubility of the latter, which frequently gives rise to errors, as it is sometimes difficult to distinguish between a very small sand granule and a colony of bacteria. Moreover, the apparatus proposed by Sedgwick prevents, to a large extent, contaminations from without that are not impossible during the process of pouring out the mixture of sand and gelatine. The sugar, of a definite size grain, is placed in a narrow glass tube of about 2 to 3 m.m. inside diameter and about 6 c.m. in length; the tube is widened out at one end into a glass cylinder of about 2 to 3 c.m. inside diameter and of about

6 c.m. long. The whole tube, containing the sugar only in its narrow end and being plugged at both ends with cotton, is sterilized by heat so as to destroy any living bacteria that may be in it. When sterilized the cotton plug is removed from the large end and the small end is connected with an aspirator. A definite amount of air is drawn through it and in its passage through the sugar it leaves all its bacteria adherent to the sugar granules. When the desired amount of air has passed through the sugar the cotton plug is replaced in the large extremity of the tube and it is then held in an almost horizontal position and gently tapped against the finger until all the sugar has been caused to pass from the small into the large part of the glass cylinder, taking its bacteria with it. When this is accomplished, about 10 to 15 cubic centimeters of sterilized liquid gelatine is poured into the large end of the tube, the sugar dissolves in it and the tube is then rolled in the horizontal position upon ice. The low temperature causes the gelatine to solidify and thus fix the bacteria at different parts upon the inner walls of the tube. They develop into colonies and can then be counted, as in the process of Petri. The advantages of this process are the solubility of the filtering medium and the diminution in the chances of contamination by bacteria from sources other than that under consideration during manipulation.

This is not the place for a detailed description and critical discussion of bacteriological methods. What has been said will suffice to indicate the general principles upon which these determinations are based. For a more minute description of the methods employed and the general conditions underlying bacteriological manipulations special works on the subject must be consulted.

CHAPTER X.

METHODS OF HEATING: STOVES, FURNACES, FIREPLACES, STEAM AND HOT-WATER THERMOSTATS.

IT is presumed that every reader of this book will admit that good ventilation is a very desirable thing, and that we should pay at least as much attention to it as to the ornamentation of buildings. But we must also bear in mind another very important fact—viz., that in cold weather satisfactory heating is even more desirable and necessary, since without it the better the ventilation the louder will be the complaints. We may write and talk as much as we please about the horrors of foul air and the importance of good ventilation, but we shall never induce people to consent to sit in cold draughts and shiver for the sake of pure air, and, in fact, we would not do it ourselves.

In preparing plans for ventilation we must, therefore, consider the methods of heating to be employed in cold weather. Heat is a force, that is, a mode of motion of the molecules of gaseous, liquid, or solid matter, and most of the heat which is of practical interest to us in this connection is, or has been, derived from the rays of the sun. Fuel of all kinds contains force stored up from the sun's rays by plants, and animal heat comes from the same source. The production of artificial heat, as it is commonly termed, for the purpose of warming or ventilating a building is usually effected by the combustion of fuel, and we can obtain only a certain limited amount of heat from a certain quantity of a particular kind of fuel. To obtain this fuel and place it where it is needed, and to provide the necessary apparatus for its combustion, and for the conveyance and distribution of the heat thus produced, requires labor, in other words, it costs money, and this cost varies greatly in different localities and with different forms of heating apparatus. The problem of the heating engineer is to obtain in each particular case satisfactory results as to temperature and ventilation with the greatest economy, and this economy must be

studied both with reference to the cost and durability of the apparatus required and the amount of fuel to be supplied. For measuring and comparing quantities of heat a unit of measure is required, and that which is most commonly used in this country is the amount of heat required to raise a pound of water 1° F., say from 32° F. to 33° F. The amount of heat required to raise one pound of water 1 degree in temperature differs slightly for different parts of the scale, and in modern scientific calculations, what is known as the British thermal unit, abbreviated B. T. U., is used, being the amount required to raise a pound of water from 50° F. to 51° F. The difference between these two thermal units need not be considered in problems of house heating. In the metric system the unit of heat is the calorie (in the plural calories) being the amount of heat required to raise a kilogram of water from 0° C to 1° C, but often the small calorie is used—*i. e.*, that required to raise one gram of water from 0° C to 1° C, as in the centimeter-gram-second, or C. G. S. system of physical units measurement.

In some heating and ventilation problems it is convenient to express the amount of heat in terms of force, and *vice versa*. The thermal unit is equivalent to 772 foot-pounds of force. The calorie is equal to 423.985 kilogram-meters, each kilogram-meter being equal to 7.2 foot-pounds, or one calorie is equal to 3.956 + thermal units.

We have chiefly to deal with the questions involving the amount of heat in different quantities of air, and of water and watery-vapor, under different circumstances, and the amount produced by combustion of given quantities of fuel, and for our purposes accurate computations are unnecessary, and the range of temperature involved is comparatively small. The specific heat, that is, the amount of heat required to heat one pound 1° F. is for water one thermal unit, increasing slightly as the temperature rises, and for air with constant pressure, involving increase of volume by expansion with rise of temperature, it is 0.2379 thermal unit. If the volume be constant, it is 0.16866 thermal unit. In these and all following computations it is assumed that the barometric pressure of the atmosphere remains constant at the standard of 29.922 inches of mercury. Under these circumstances one pound of air at 32° F. contains 12.387 cubic feet, or 1 cubic foot of air weighs 0.080726 pound, or 1 litre of air = 0.035317 cubic foot and weighs 1.293187 grams, the gram being equal to 0.00220462 pound.

As air under constant pressure expands as the temperature rises, a cubic foot of air weighs less when its heat increases.

The following table shows the weight of dry air at different temperatures :

WEIGHT OF DRY AIR AT DIFFERENT TEMPERATURES, THE BAROMETER STANDING AT 29.92 INCHES OF MERCURY.

Cubic Feet of Air.	WEIGHT IN POUNDS AT TEMPERATURE F.																
	32°	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
100	8.07	8.02	7.94	7.86	7.79	7.71	7.64	7.57	7.50	7.43	7.36	7.29	7.23	7.16	7.10	7.03	6.97
200	16.14	16.04	15.88	15.72	15.58	15.42	15.28	15.14	15.00	14.86	14.72	14.58	14.46	14.32	14.20	14.06	13.94
300	24.21	24.06	23.82	23.58	23.37	23.13	22.92	22.71	22.50	22.29	22.08	21.87	21.69	21.48	21.30	21.09	20.91
400	32.28	32.08	31.76	31.44	31.16	30.84	30.56	30.28	30.00	29.72	29.44	29.16	28.92	28.64	28.40	28.12	27.88
500	40.35	40.10	39.70	39.30	38.95	38.55	38.20	37.85	37.50	37.15	36.80	36.45	36.15	35.80	35.50	35.15	34.85
600	48.42	48.12	47.64	47.16	46.74	46.26	45.84	45.42	45.00	44.58	44.16	43.74	43.38	42.96	42.60	42.18	41.82
700	56.49	56.14	55.58	55.02	54.53	53.97	53.48	52.99	52.50	52.01	51.52	51.03	50.61	50.12	49.70	49.21	48.79
800	64.56	64.16	63.52	62.88	62.32	61.68	61.12	60.56	60.00	59.44	58.88	58.32	57.84	57.28	56.80	56.24	55.76
900	72.63	72.18	71.46	70.74	70.11	69.39	68.76	68.13	67.50	66.87	66.24	65.61	65.07	64.44	63.90	63.27	62.73

The following table shows the amount of heat required to raise the temperature of a given weight of air through a given number of degrees Fahrenheit.

NUMBER OF THERMAL UNITS REQUIRED TO HEAT A GIVEN QUANTITY OF DRY AIR A CERTAIN NUMBER OF DEGREES FAHRENHEIT.

Pounds of Air.	HEATED.								
	1°_{33}	2°_{34}	3°_{35}	4°_{36}	5°_{37}	6°_{38}	7°_{39}	8°_{40}	9°_{41}
100	23.79	47.58	71.37	95.16	118.95	142.74	166.53	190.32	214.11
200	47.58	95.16	142.74	190.32	237.90	285.48	333.06	380.64	428.22
300	71.37	142.74	214.11	285.48	356.85	428.22	499.59	570.96	642.33
400	95.16	190.32	285.48	380.64	475.80	570.96	666.12	761.28	856.44
500	118.95	237.90	356.85	475.80	594.75	713.70	832.65	951.60	1070.55
600	142.74	285.48	428.22	570.96	713.70	856.44	999.18	1141.92	1284.66
700	166.53	333.06	499.59	666.12	832.65	999.18	1165.71	1332.24	1498.77
800	190.32	380.64	570.96	761.28	951.60	1141.92	1332.24	1522.56	1712.88
900	214.11	428.22	642.33	856.44	1070.54	1284.66	1498.77	1712.88	1926.99

TABLE SHOWING THE VOLUME OF DRY AIR AT CERTAIN DEGREES OF FAHRENHEIT, THE VOLUME AT 32 DEGREES BEING 1.000.

Temperature, Fahrenheit.	Volume.	Temperature, Fahrenheit.	Volume.
32°	1.000	60°	1.057
35°	1.006	65°	1.067
40°	1.016	70°	1.077
45°	1.026	75°	1.087
50°	1.036	80°	1.097
55°	1.046		

NUMBER OF THERMAL UNITS REQUIRED TO HEAT A GIVEN QUANTITY OF DRY AIR A CERTAIN NUMBER OF DEGREES FAHRENHEIT, COMMENCING AT 32° F.

Cubic Feet.	HEATED.								
	1°	2°	3°	4°	5°	6°	7°	8°	9°
100	1.92	3.84	5.76	7.68	9.60	11.52	13.44	15.36	17.28
200	3.84	7.68	11.52	15.36	19.20	23.04	26.88	30.72	34.56
300	5.76	11.52	17.28	23.04	28.80	34.56	40.32	46.08	51.84
400	7.68	15.36	23.04	30.72	38.40	46.08	53.76	61.44	69.12
500	9.60	19.20	28.80	38.40	48.00	57.60	67.20	76.80	86.40
600	11.52	23.00	34.56	46.08	57.60	69.12	80.64	92.16	103.68
700	13.44	26.88	40.32	53.76	67.20	80.64	94.08	107.52	120.96
800	15.36	30.72	46.08	61.44	76.80	92.16	107.52	122.88	138.24
900	17.28	34.56	51.84	69.12	86.40	103.68	120.96	138.24	155.52

NUMBER OF THERMAL UNITS REQUIRED TO HEAT A GIVEN QUANTITY OF DRY AIR A CERTAIN NUMBER OF DEGREES CENTIGRADE FROM 0° C.

Cubic Meters.	HEATED.								
	1°	2°	3°	4°	5°	6°	7°	8°	9°
1	1.22	2.44	3.66	4.88	6.10	7.32	8.54	9.76	10.98
2	2.44	4.88	7.32	9.76	12.20	14.64	17.08	19.52	21.96
3	3.66	7.32	10.98	14.64	18.30	21.96	25.62	29.28	32.94
4	4.88	9.76	14.64	19.52	24.40	29.28	34.16	39.04	43.92
5	6.10	12.20	18.30	24.40	30.50	36.60	42.70	48.80	54.90
6	7.32	14.64	21.96	29.28	36.60	43.92	51.24	58.56	65.88
7	8.54	17.08	25.62	34.16	42.70	51.24	59.78	68.32	76.86
8	9.76	19.52	29.28	39.04	48.80	58.56	68.32	78.08	87.84
9	10.98	21.96	32.94	43.92	54.90	65.88	76.86	87.84	98.82

From these tables it is easy to calculate the amount of heat required to raise the temperature of any given quantity of air through any given number of degrees of temperature. Suppose, for example, that we wish to supply to a hospital ward 72,000 cubic feet of air per hour and that we are to provide for heating it from 32° to 70° or 38° F. Then :

70,000	cubic feet	heated	30° =	40,320	thermal	units.
70,000	"	"	8° =	10,752	"	"
2,000	"	"	30° =	1,152	"	"
2,000	"	"	8° =	307	"	"
Total..................				52,531	"	"

In round numbers and for rough calculations we may assume that one thermal unit will heat 50 cubic feet of air 1° F. Applying this rule to the above figures we have $72,000 \div 50 = 1,440 \times 38 = 54,720$ thermal units, a slight excess over the figures derived from the table.

Heat is usually said to be communicated from one body to another by three processes—viz., radiation, conduction and convection. Radiant heat passes from the heated body in straight lines in every direction until it is intercepted by some other body. It diminishes for a given area as the square of the distance from its source, and it does not appreciably heat the air or gases through which it passes. For efficient heating by pure radiant heat the temperature of the heating body must be comparatively high, at least that of a dull red heat of iron, the typical form of this kind of heating being by the glowing coals in an open grate or fireplace. Conducted heat passes from one particle of matter to another when they touch—*i. e.*, are separated by insensible distances. If one of the particles of matter is free to move, as in liquids and gases, it may carry the heat which it has received to another point and there part with it—this being what is called convection, which is only a particular form of conduction. Heat is conducted readily from solids to liquids or gases, and from these to solids, but it passes only to a very limited extent from one particle of liquid or gas to another particle of liquid or gas.

The heating of a room is technically said to be effected by direct radiation, by indirect radiation, by direct-indirect radiation, or by combinations of these methods. In this sense direct radiation means that the heating surfaces are placed in the room to be warmed, and are not connected with the air supply, so that the incoming air is not warmed. Indirect radiation means that the room is heated by air which has been warmed by being brought into contact with heated

surfaces placed in some other room, usually in the basement or cellar. Direct-indirect radiation means that the heating surfaces are placed in the room to be warmed, and have fresh air brought in around or between them, so that it is warmed.

Direct radiation includes fireplaces, ordinary stoves, and pipes or radiators heated by steam or hot water. Of these the fireplace or open grate is the only one which really heats entirely by radiation—the greater part of the heat furnished by stoves and radiators being convected—that is, conveyed by heating the air which flows up in contact with the hot surfaces. It also includes systems for heating the walls or floor of the room by various means. When a room is said to be heated by direct radiation it may in most cases be taken for granted that it has no special provision for the supply of fresh air, and, therefore, is unventilated. There are, however, some exceptions to this rule, for some engineers have endeavored to use direct radiation, and, at the same time, to supply fresh air which is not to be warmed. Their theory is that it is healthier and more pleasant to breathe air of a temperature of from 35° F. to 55° F. than to breathe air at a temperature of 65° F. or 70° F., and hence that a proper system of heating should supply by radiation from fires, walls, etc., the amount of heat requisite for comfort, and, at the same time, allow the air to remain comparatively cool.

This is the teaching of Mr. Leeds,[1] and also that of M. Emile Trélat, who argues that the cooler the air the greater its density, and, therefore, the more oxygen it contains in a given bulk,[2] and the more oxygen the better for respiratory purposes.

There is, however, abundance of oxygen in ordinary air at the temperature of 70° F., and a man's sensations while walking in open air of this temperature, provided it does not contain too much moisture, are very satisfactory. The lower the temperature of the air inhaled the greater (other things being equal) will be its capacity when heated to 98° F. in the lungs for taking up moisture from the lungs and air passages, and probably the greater also the facility with which certain volatile organic products will be excreted with the exhaled breath, but there is no evidence that it is any healthier to breathe air at 50° F. than at 70° F. provided the supply of fresh air is abundant.

Direct-radiation systems are more used than any others because they are cheaper in construction, and do not require a fresh-air supply

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[1] Leeds, L. W. A Treatise on Ventilation, New York, 1871.

[2] Théorie du Chauffage des Habitations, Rev. d' hyg. XIII., 1891, p. 1,087.

to enable them to give the necessary heat, as is the case with the indirect system—hence they can often be run at much less cost for fuel. This is not the case with the open fireplace, which is the most costly, as regards fuel, of all the methods of warming—nevertheless, for small rooms in private houses, when the temperature of the external air is not below 32° F., the open grate will be preferred by many to all other means of warming, and it is always well to provide for it in the plans of such buildings, for it furnishes a good outlet flue whether a fire be used in it or not. It is an agreeable addition to other means of heating, but it is dangerous, difficult to regulate, productive of dust and noise, and requires considerable labor.

In very cold weather the fireplace is by no means satisfactory as a source of heat, and in our Northern cities it should be considered, so far as heating is concerned, as merely supplementary to the furnace or steam heating, or even to the common air-tight stove. It wastes from 75 to 90 per cent. of the fuel consumed in it, so far as the work of warming the room is concerned. Although this great waste of heat from the ordinary fireplace is universally admitted, there have been but few careful observations made on the subject. Among these are those reported by Mr. J. P. Putnam, in his very interesting book, "The Open Fireplace in all Ages." Boston, 1881.

Although, as its title indicates, this work is largely historical, yet it is much more than this, for the author has not been satisfied to be merely a collector and critic of the work of others, but has undertaken to investigate for himself the action of fireplaces and heaters of various kinds, and gives as the result some valuable original data, to which, it is to be hoped, that architects, furnace manufacturers and heating engineers will give special attention. The first series of experiments detailed by Mr. Putnam simply confirm the statements of Morin and Péclet as to the enormous loss of heat, and the consequent waste of fuel consumed in producing it, in the use of an ordinary fireplace. He found that in using dry pine wood only about 6 per cent. of the heat generated by the fuel was utilized in warming the room. In a room 29′x20′x10′, six and a half pounds of dry wood raised the average temperature of the room only a little over 1° F., although the heat generated was sufficient to raise the temperature of 14 rooms of equal size from freezing to 68° F.

Another series of experiments was made with ventilating fireplaces of two different patterns set in the same room in which the trials of the common fireplace were made. In the first of these, made with what is called the fireplace heater, about 13 per cent. of the heat from the

burning wood was utilized, or about twice as much as in the ordinary fireplace. The second form of apparatus tried was the Dimmick heater, and Mr. Putnam calculates that with this 18 per cent. of the heat produced was utilized.

The point to which attention is called is not the relative value of this or that form of apparatus, for, as a matter of fact, the data given are not sufficient to determine the point with precision ; but it is, that we have in this work an attempt to employ the experimental method in a scientific manner, in order to settle the question of such relative values, and that this is the only possible method by which we can obtain positive scientific data on the subject. It is not sufficient to try experiments. Every proprietor of a furnace or heater, of any kind, has done that, and is prepared to say that he has satisfied himself by experiment of the value of his apparatus. To be of value the experiments must be made and the results must be recorded in a scientific manner. Mr. Putnam has endeavored to do this by testing the different forms of apparatus, as far as possible, under the same circumstances, placing them successively in the same room, using the same kind of fuel and for the same length of time, and then recording the results by instruments of precision—by the thermometer and the anemometer—instead of giving vague and useless opinions as to whether one was better than another.

It is true, as mentioned above, that the data are not as complete as could be wished; for example, we are not told in each case how many cubic feet of air escaped at the top of the chimney, and at what temperature, during the time of each experiment. This must be observed, and not merely calculated or inferred, in order to determine the number of heat units thus escaping, but if we could only obtain, from reliable authority, data for every form of heating apparatus similar to those given in this work, it would be a long stride toward placing the subject of heating and ventilation on a sound basis.

As this book is thus recommended, it seems desirable to point out what seems to be a fallacious line of reasoning in its first chapter—a fallacy which, while not materially detracting from the interest and value of the work, should nevertheless be understood by its readers. The first chapter begins as follows:

"That great radiator of heat to all living beings, the sun, furnishes those beings with the kind of heat best suited to support the life which it has developed, namely, that of direct radiation. If we would only accept this lesson, repeated every day as if for the purpose of giving it all possible emphasis, in a manner the most impressive, and with appa-

ratus the most magnificent that Nature can furnish or the mind of man imagine; if we would accept the lesson and endeavor to heat our houses after the same principles, these houses might be made as healthy as the open fields.

"We should be prompted to respect more the open fireplaces as furnishing the best substitute for the life and health-giving rays of the sun, and to discard all such systems of heating as are opposed in principle to that employed by Nature."

Precisely this form of argument is used to advocate vegetarianism, long hair, going naked, communism, and every other sort of "ism" and "pathy" which its advocates choose to consider in accord with what they are pleased to call "nature." The notion that in order to make our houses as healthy as the open fields, all that is necessary is to heat them by direct radiation, will simply bring a smile to the face of every educated physician or sanitarian. The author himself forgets his commencing axiom very soon, for on page 10 we find him stating that ideal perfection would imply that the supply of fresh air introduced into the house shall be warmed in winter to a temperature somewhat below that of the room, and all of his suggestions in the latter part of the book for so arranging the flues of open fires as to warm the fresh-air supply of the room relate to increasing the supply of heat by indirect and not by direct radiation.

It is, in fact, in this direction only that practical improvement in the economics of heating is to be hoped for, since it is not possible to increase the amount of heat to be obtained by direct radiation from a given amount of fuel, and at the same time secure a sufficient ventilation, beyond what the fireplaces of Gauger and Rumford will effect. To secure the best effects from direct radiation a high temperature with a correspondingly rapid consumption of fuel is necessary.

To say that the heating of rooms by close stoves, or by steam or hot-water radiators placed in the room to be warmed, is heating by direct radiation, is the phrase in common use; the greater part of the effect of such appliances is due not to radiant, but to convected heat—to the circulation of air heated by coming in contact with them.

All this is understood by Mr. Putnam, who says that the system of tubes which he proposes to arrange above the fireplace to heat the fresh air should properly be called a convector.

We close these remarks by quoting a passage from the book, which carries its own moral. The picture of the proprietors and workmen

standing around and staring with astonishment at the results of the test ought to have been given by the pencil as well as by the pen :

"Furnace makers will claim that the peculiar kind of cement they use, or their peculiar method of hammering the joints, will prevent leakage and stand fire. The writer visited a furnace advertised by the makers to be absolutely gas-tight. The joints were numerous. In some joints cast iron was connected with wrought. Pipes of cast iron were set into wrought-iron plates—an arrangement the reverse of that used in the Dunklee furnace. To this the writer particularly objected, and inquired of the makers if they could warrant the furnace to stand tests at these points. The method of making these joints was, they claimed, *peculiar*.

"No cement was used, and so great was the care bestowed on each joint that leakage was a sheer impossibility. A fine, new furnace was exhibited to show the excellence of the workmanship. The writer still objected, until challenged by the makers to give proof of any of the numerous furnaces put up by the company having ever leaked gas. Without taking the time to visit any or all of the 500 or more gentlemen whose letters of recommendation adorned the descriptive circular of the firm, the writer expressed himself satisfied if the fine, new sample furnace then on exhibition would itself stand the test. With the assurance that he was at liberty to make any reasonable test he pleased, he ordered the furnace to be turned over and water poured into all the joints. To the complete astonishment of the proprietors and of the careful workmen standing around, the water which was poured in poured out again through nearly every one of the score of careful joints, until the furnace seemed to dissolve and float away in its own tears." (Pp. 119–20.)

The majority of those who write on the beauties of warming by open fireplaces in this country have had no experience of fireplace warming with the external temperature at 10° F., or lower.

Some trials were made several years ago, in our small army hospitals, of double fireplaces, placed back to back, and so arranged that the fresh air was introduced between them, and warmed before it escaped into the room. With anthracite coal these double-ventilating fireplaces worked very well when the external temperature was above 30° F., giving excellent ventilation and very fair heating ; but when the external temperature was near zero, and when only wood or soft coal was available, it seemed as if the more fire was made the colder it got, since the incoming air was not sufficiently warmed, and at times it appeared as if the inmates might be frozen to death by their own fire-

places. The great majority of the small dwelling houses, or living rooms, in this country, are heated by stoves, because this is the cheapest method. Architects and engineers seldom or never have anything to do with the plans or specifications for buildings of this kind, since their builders are usually their own architects.

There are a number of patent stoves, which act upon the principle of the ventilating fireplace, but the amount of air introduced and warmed by them is usually small. For small rooms, occupied by only one or two persons, they answer very well, but in a large room, containing many persons, it is extremely difficult, if not impossible, to secure a satisfactory introduction and distribution of fresh air by any form of stove placed in the room itself. The stove must be placed below the room to be warmed ; in other words, it must be converted into a furnace. The great majority of hot-air furnaces as actually used are unsatisfactory, and special sources of danger to health, but this is not so much the fault of the furnaces themselves as of the manner in which they are set and adjusted. They are better than stoves in this respect, that satisfactory heating cannot be secured by them without the introduction of air into the room to be heated, but the air that is introduced by them is often of a very unsatisfactory quality.

If a building is to be heated by a hot-air furnace, the following points should be borne in mind in its selection and adjustment :

First.—In 99 out of every 100 buildings in this country in which this method of heating is used, the furnace is too small. The result of this is, that in cold weather, in order to secure comfort, it is necessary to raise the heating surface to a high temperature, often to a red heat. The contraction and expansion due to such great changes of temperature soon loosen the joints of furnaces built up of several pieces, and permit the escape of the gases of combustion into the fresh-air supply. Of these gases, carbonic oxide and sulphurous acid are the most hurtful.

The sulphur compounds, when present in harmful quantity, are so perceptible to the smell and create irritation of the air passages to such an extent as to soon call attention to the evil and lead to attempts to remedy it. Carbonic oxide is odorless. When present in small quantities, it produces a peculiar feeling of discomfort, somewhat as if a tightly-fitting band were drawn around the head, increasing to a dull, persistent headache, with slight giddiness, languor and disinclination for either mental or physical exertion. This gas will pass through red-hot cast iron, and this fact is much insisted on by the manufactur-

ers of wrought-iron, soapstone or brick furnaces. The special danger on this account from a cast-iron furnace is probably extremely small; it is much more due to defective castings containing sand holes, or to badly-fitting joints.

As Mr. E. S. Philbrick has pointed out,* wrought-iron furnaces are by no means faultless as regards leakage, "for if often heated to redness they suffer such strains by the expansion and contraction which always accompanies heating and cooling, that the joints will be apt to fail, or other cracks open in a little time." Moreover, wrought iron oxidizes much more rapidly than cast iron, and will fail sooner from this cause. It may be safer when new, but is more perishable. Brick, clay or tile furnaces are not much used in this country. They take up much more room than iron furnaces, but have the advantage of giving a much larger heating surface at a comparatively low temperature.

Second.—As furnaces are usually set, there is no provision for mixing cool air with the heated air. The result of this is, that the air is delivered in the room at a high temperature—often at 140° F., and sometimes higher—and the only way to prevent the room from becoming too warm is to close the register, which, of course, shuts off the supply of fresh air.

Third.—The source of air supply to a furnace is often very unsatisfactory. Sometimes it is taken directly from the cellar itself, in which case it is almost sure to be contaminated with gases escaping from the furnace door, while the cellar itself contains decaying vegetables, slop buckets, and perhaps an empty bell trap, giving free communication with the sewer; or the air box from the outer air to the furnace passing through the cellar may have so many cracks and loose joints that the cellar air finds an easy entrance to it. The fresh-air supply should not be brought in through an underground duct without taking special precautions to have it air-tight, and it should not pass across or near a drain or sewer.

As a rule, architects make no special provision for the fresh-air supply to a furnace, and the furnace setter is left to adjust this as best he can, the result being that he will often select that method which involves the least trouble and expense, but which also will give the least satisfactory result.

Fourth.—A furnace is usually placed near the center of a building, the object being to have the flues conveying the heated air from it

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* See Material for Stoves, *The Sanitary Engineer*, Vol. III., page 3.

as short and with as rapid an ascent as possible. Horizontal flues for heated air are very undesirable, as the friction in them checks the current and involves loss of heat. The direction of the wind has a great influence on the action of hot-air flues, and for this reason it is better to place the furnace not in the center, but toward that side of the house against which the winter winds blow most frequently and strongest. In this vicinity this will be toward the northwest. If a building of large area is to be warmed by furnace heat, it will be much better to use two or three furnaces distributed over the area than one large central one.

It is not proposed to discuss the merits of the various patterns of furnaces now in the market, but it may be said in regard to them that those which have the fewest joints and the largest amount of radiating surface in proportion to the size of the fire box, are to be preferred—other things being equal—and that it is very poor economy to buy a furnace which is not large enough to furnish, in the coldest weather, all the heat required, without bringing the fire pot to a red heat.

In this country nearly all large public buildings are heated by steam, and in preparing plans for such edifices our architects take it for granted that this method will be employed, unless specific directions to the contrary are given by the building authorities.

The cases in which hot-water apparatus is used in such buildings are comparatively few, this form of heating in this country being for the most part confined to dwelling houses, hospitals and greenhouses.

The reasons why steam has thus obtained the preference over hot water are worth considering. As a rule, our architects give little attention to the details of heating apparatus, and prepare their plans without any special reference to such details, other than providing space and a chimney flue for the boiler, and other flues in the walls.

They rely for all details upon those firms who supply heating apparatus, and are guided by their advice to a great extent in the selection.

The firms which make a business of furnishing steam and hot-water apparatus are comparatively few, for the business is one which requires large capital; but, few as they are, not all of them employ a properly-educated engineer to prepare their plans and specifications, or to supervise the setting of their apparatus.

Now, it is very much easier to plan and set up a steam-heating apparatus which will work, than to do the same with a hot-water apparatus. Please observe that the statement is "which will work,"

and not "which will work properly, and be also the most economical as to construction and maintenance;" and there are also omitted in this connection all considerations as to the securing of proper ventilation.

In a steam apparatus it is not necessary that the boiler shall be on a lower level than the heating surfaces, and much greater inequalities and more frequent alterations in the levels of the flow and return pipes are permissible than is the case with hot water. In a hot-water apparatus a mistake of a few inches in the height of a pipe may prevent the working of the whole system. In a steam apparatus the injurious effects of miscalculation as to areas of pipes or of radiating surface may, to a considerable extent, be overcome by increasing the pressure in the boiler, although at an undue expense for fuel, while this can only be done within very narrow limits in a hot-water apparatus.

As the radiating surfaces in steam heating are kept at a higher temperature than when hot water is used, the radiators may be made smaller and more compact, and thus be more convenient in some places than the larger hot-water coils. It is also easier to "scamp" a steam-heating job than a hot-water one.

The very general use of steam as a source of power has made a large number of workmen familiar with the boilers and fittings required for its use, and these can be everywhere obtained without difficulty.

For all these reasons, in addition to the important one that the plant for a steam-heating apparatus is cheaper than for a hot-water one, it has come to pass that there are but a few firms in this country which recommend hot-water apparatus under any circumstances, or which are willing to undertake repairs or alterations in such apparatus. Hood states that "the first cost incurred for the erection of the two kinds of apparatus will differ but little when the work is done in an equally substantial manner; but the wear and tear and repairs of a hot-water apparatus will be less than that of a steam apparatus, as in the former there is absolutely nothing that can wear out except the boiler, while in a steam apparatus there are various things which constantly require attention and repair in addition to the greater amount of wear in the steam boiler itself, caused by the large quantities of sediment which requires to be constantly removed."

The principal disadvantages of a steam-heating apparatus are as follows :

First.—It requires constant attention to keep up the supply of heat, for as soon as the production of steam in the boiler ceases the

radiating surfaces cool rapidly. This is claimed as an advantage in the steam-heating apparatus for rooms that are to be occupied but a few hours each day, on the ground that it furnishes the heat only when it is actually wanted, and is, therefore, more economical than a hot-water apparatus from which heat continues to radiate for several hours after the necessity for it has ceased. While this is true to a certain extent, it should be remembered that to secure comfort in cold weather the walls, floors, etc., of a room must be warmed to a certain point, and that heat must be expended in doing this whenever these surfaces are allowed to cool, so that the shutting off the supply of heat is by no means a clear gain.

Second.—Owing to the high temperature of steam radiators as compared with hot-water ones, it is more difficult with the former to regulate the supply of heat in accordance with the demands of our very variable climate without interfering with the amount of air supply. As steam-heating apparatus is usually arranged, the only way to diminish the heat is to either close the register, which cuts off the supply of fresh air, or to turn off the steam from the radiator, which will give an insufficient supply of heat. The result is that the great majority of steam-heated rooms are, during many days in the year, too hot, and at the same time have an insufficient supply of fresh air, producing much the same kind of discomfort as an ordinary hot-air furnace, although in a somewhat less degree. This evil can be remedied in several ways. The first is to arrange each set of radiators in several distinct sections, in each of which the flow of steam can be controlled independent of the others, so that when but little heat is required only one section need be used, and so on in proportion to the external temperature.

Such a radiator, as arranged by Baker, Smith & Co., of New York, is shown in Fig. 23.

The radiator is divided in the base by partitions *p p*, so as to separate each row of tubes into a different radiator, as it were ; each radiator or section having its own set of valves—*i. e.*, steam, return and air valve. The pipe *d* is the steam supply to a header *a*, into which are nipped as many valves *c*, as there are sections in the radiator These valves in turn are connected with the base of the radiator by right and left-handed nipples *b*. In like manner the return valve *c'*, header *a'*, and return pipe *d* complete the return end of the radiator. These heaters are made as wide as six sections, and have small holes *e*, through the base, to allow a somewhat better contact of the air within the pipes than could be had with wide bases if they were not perforated.

Practically, such direct radiators managed by inexpert hands are apt to give trouble by noise or by freezing of condensed water in some of the pipes. Where the heaters are connected with a blower system under the management of an engineer, this method of shutting off a part of the system may work very well.

It is also possible in many cases to so arrange the apparatus that instead of the usual valves on the inlet and outlet pipes to each radiator, both of which must be entirely closed or wide open, a single

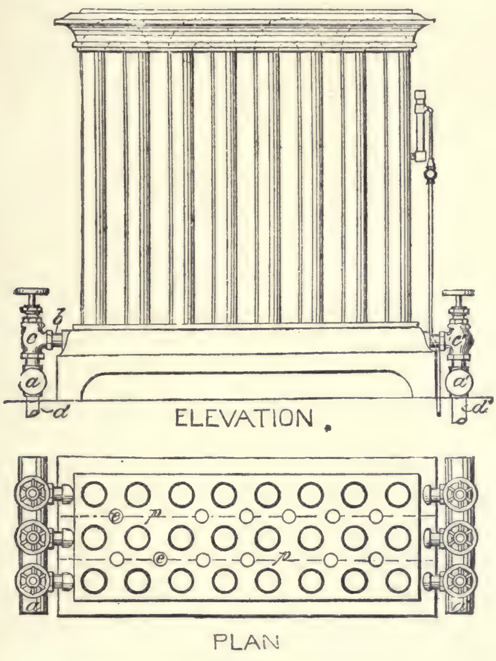


FIG. 23.

valve, such as the one invented by Mr. Tudor, and described on page 616, Vol. VIII., of *The Sanitary Engineer*, placed on the inlet will control the steam supply without risk of condensed water being driven back into the radiator.

A second mode of remedying the evil is to so arrange the air ducts and flues that by the movement of a valve the air can be at pleasure made to pass either wholly in contact with the radiating sur-

faces or wholly separate from them, or partly in one way and partly in the other, in such proportions as may be desired. Various forms of by-passes for this purpose are described in the following chapter. By this method very excellent results may be secured, but it requires careful adjustment of the valves and flues and constant supervision.

Third.—The noises produced in a steam-heating apparatus, due to the presence of steam and water in the same pipe, but flowing in opposite directions, and technically known as "water hammer," are often very disagreeably prominent, especially where a series of radiators in a horizontal line discharge their condensed water into one return. Water hammer, however, can be avoided if the apparatus is properly constructed, and in such a case as that just supposed it will be prevented by keeping the return on a level below the water line in the boiler.

Fourth.—A steam-heating apparatus is somewhat more dangerous than a hot-water one, but if it is set and managed with good ordinary intelligence the danger is very slight. The automatic adjustments are now so satisfactory in steam boilers for this class of work that an explosion is hardly possible, and the danger of fire from steam pipes is very small. Such danger, however, exists, and it should be remembered in carrying steam pipes on or near wooden surfaces.

It is not my purpose to give details of forms of apparatus, methods of construction, etc., such as should be indicated in the plans and specifications for the steam or hot-water heating of a particular building. What I do aim at is to give to the architect or builder the information which will enable him to fix the size and location of the radiators needed, the size and location of the mains and accelerating coils, the size and location of the boiler, and the size and location of the chimney for the boiler. He can then furnish these data to the heating engineers or firms whom he prefers and ask them to state their price for the work, and give details as to the particular kind of boiler, valves, radiators, etc., which they propose to use.

A general specification to the effect that the building must be warmed to 70° F. when the external air is at zero, or even that it must be so warmed with a certain specified amount of change of air for each room is practically worthless if the work is to be let by contract to the lowest bidder.

It is possible to construct a heating apparatus which will meet such requirements for a year or so—just long enough to enable the contractor to obtain his final payments, and which will soon after break down utterly—and to furnish such an apparatus for a

price 20 or 30 per cent. lower than that which would be demanded for one which will do its work for from 10 to 20 years with only trifling repairs. The broad outlines of the system of heating and ventilation to be used should be decided on in the sketch plans, and all smoke and air flues, radiators, accelerating coils and mains should be accurately located, and their sizes defined on the first set of working drawings.

Taking the approximate estimate given above, that one thermal unit will heat 50 cubic feet of air 1 degree, which is from 2 to 5 feet less than the actual quantity and is therefore a safe estimate, we have next to consider the amount of heat that is given off from heating apparatus.

The amount of heat given off from wrought or cast-iron pipes heated by steam or hot water varies from 1.15 to 2.25 thermal units per hour per square foot of radiating surface for each degree Fahrenheit of difference between the temperature of the pipe and that of the surrounding air, the difference depending upon the shape and relations of the surfaces to each other and the relative amounts of heat removed by direct radiation or by convection. For a direct radiator with vertical tubes it may be taken as 1.75 thermal units—for an indirect radiator as 1.15 thermal units, per square foot per hour for each degree of difference in temperature. Hence, to find the number of square feet of radiating surface required to heat a given supply of air to a given temperature, multiply the number of cubic feet of air per hour by the difference between the temperature of cold-air supply and that to which it is to be heated and divide it by 50, which will give the number of thermal units required, and by dividing the number of thermal units by the difference between the temperature of the radiator and that of the surrounding air multiplied by 1.75 for direct and by 1.15 for indirect radiators, the number of square feet of surface required will be found. For example, if a room is to have 6,000 cubic feet of air supply per hour, to be heated from zero to 70° F. by a direct-steam radiator whose temperature is 210° F., then $\frac{6{,}000 \times 70}{50} = 8{,}400$ thermal units, and $\frac{8{,}400}{140 \times 1.75} = 34.3$ square feet of radiating surface are required to do this work. In addition to this, the loss of heat from windows and walls must be provided for, as will be explained hereafter.

Tredgold's rule is, mutiply the number of cubic feet of air to be heated per minute by the difference between the temperature at which the room is to be kept and that of the external air expressed in degrees Fahrenheit and divide the product by 2.1 times the difference between

200 and the temperature of the room; this will give the number of square feet of radiating surface, which in the foregoing example would be 25.6.

In the preparation of plans and specifications for the heating of a building by hot water or steam, the first thing to be done is to prepare a schedule showing for each room and hall the dimensions, the number of cubic feet of air space, the amount of wall surface exposed to the outer air stated in equivalents of square feet of glass surface, and the number of cubic feet of air to be supplied per hour if special ventilation is to be provided. The exposure of the room—that is, the point of the compass towards which the windows look—whether it is a corner room, and whether it is sheltered from wind by trees, neighboring buildings, etc., should also be noted. From these data, taken in connection with the lowest external temperature to be provided against, and with a knowledge of the general conditions of the locality as to prevailing winds in winter, exposure, etc., there is to be calculated for each room the number of square feet of radiating surface of the temperature which it is proposed to use to maintain the temperature of the room at the point at which it is desired to keep it during the coldest weather.

This will of course give an excess of radiating surface over that which will be needed in moderate weather, and special arrangements must be made to meet this difficulty, as will be explained hereafter.

The amount of heating surface required for each room is that required to make good the loss by radiation from the walls of the room *plus* the loss due to convection of heat by the air admitted to and escaping from it, and is computed from formulæ deduced from the laws governing the cooling of heated bodies.

A heated body, like a steam pipe or radiator, if placed in an open space where the air can circulate freely around it, parts with its heat by radiation and by convection through the air. For such a body, the loss of heat from which is constantly replaced by the steam passing through it, so that its temperature may be taken as constant, the formulæ given by Peclet when the temperature of the room is about 12° C. and of the pipe about 100° C., are:

(*a*) Loss by radiation $= R = Kt\ (1 + 0.0056t)$, K being a coefficient depending on the nature of the surface and t the excess of temperature of the pipe; and

(*b*) Loss by air convection $= A = K't\ (1 + 0.0075t)$ K' being a co-efficient depending on the form and dimensions of the body and t the excess of temperature.

For cast-iron surfaces formula (a) becomes

(c) $R = 124.^{72}. Ka^{t'} (a^{t} - 1)$, in which t' is the temperature of the locality, $a = 1.0077$, and $K = 3.17$.

From these formulæ, taken in connection with the tables of values of the co-efficients K and K', have been prepared such tables as those given in the treatise of Box on heat and in Hood's treatise on warming.

These formulæ and tables are never used in calculating the amount of radiating surface required for different rooms and buildings, much shorter and simpler rules being employed, and no attempt being made to secure just enough radiating surface and no more, but an extra allowance being made to make sure that there shall be enough.

The common rule-of-thumb method of most workmen in the steam-heating business is, where the external temperature does not fall below zero, to make an average allowance of 1 square foot of radiating surface to each 100 cubic feet of space to be heated, and then to increase or decrease in different rooms, according to their exposure, etc. Hood's rules of this kind for dwelling rooms call for about 12 square feet of steam radiating surface, or 16 square feet of hot-water heating surface per 1,000 cubic feet of space, to maintain a temperature of 70° F. with the external air at 10° F. The American practice—to heat from zero to 70° F. with low-pressure steam—gives for dwelling houses with indirect radiation about 1 square foot of radiating surface to from 40 to 60 cubic feet of space, according to exposure: for large office buildings, hotels, etc., mostly direct radiation, 1 square foot of radiating surface to 75 cubic feet of space: and for large halls and churches, 1 square foot of radiating surface to from 90 to 120 cubic feet of space. Such calculations are, however, only useful for preliminary rough estimates as to cost, etc.

In prescribing the size of a furnace or stove, 1 square foot of its heating surface is usually taken as equal to 6 square feet of steam-heated radiator, or to heating about 300 cubic feet of space.

For the final calculations, where great accuracy is not desired, several simple formulæ are in common use. Probably those most often employed by the best class of steam-heating engineers in the United States are those given by Mr. Baldwin in his well-known writings on steam heating, and these are as follows:

I. To obtain the amount of radiating surface required for a given room to compensate for heat lost by radiation from windows, doors and walls. Take the difference in temperature in degrees Fahrenheit between the lowest outside temperature to be provided for and the temperature at which the room is to be kept, and divide it by the

difference in degrees Fahrenheit between the temperature of the steam pipes and the temperature at which the room is to be kept. Multiply the quotient thus obtained by the number of square feet of glass *plus* the number of square yards of external wall surface in the room and the product will be the number of square feet of radiating surface required.

Suppose, for example, that we have a room which has 36 square feet of window-glass surface and 20 square feet of external-wall surface besides the windows, that is to be kept at a temperature of 70° F. when the external temperature is 10 degrees below zero, and that it is to be heated by direct radiators supplied with low-pressure steam, which radiators may be taken as having a temperature of 210° F. Then, $\frac{80}{140} \times 56 = 32$, which is the number of square feet of radiating surface required. But this does not provide for any leakage of air through cracks and crevices or for any change of air by ventilation. In the above example it is supposed that the external walls are of brick, plastered, such walls having from one-ninth to one-tenth the power of transmitting heat which ordinary window glass has, and hence we reckon 1 square yard or 9 square feet of wall as equal to 1 square foot of glass. If the lowest external temperature to be provided for be taken as zero Fahrenheit, we may assume that half a square foot of radiating surface at 210° F. will be required for each square foot of glass or square yard of external wall.

We do not take into account the internal walls in this calculation, because we assume that they are next to heated rooms or halls, but if this is not the case they should be reckoned as external walls. Having thus obtained the amount of radiating surface required to compensate for loss of heat through windows and walls, the next thing is to calculate the amount of radiating surface which will be needed to heat the cold air coming into the room, or, in other words, to supply the heat carried out of the room by the escape of warm air.

II. For air heating the rough formula is, multiply the number of cubic feet of air per hour by the number of degrees Fahrenheit which it is to be heated and divide the product by 12,500. The quotient is the number of square feet of radiating surface required. For example: in the room above referred to, let us suppose its cubic contents to be 1,700 cubic feet, that it is on the side of the building exposed to winter winds, and that the usual amount of leakage around windows and doors exists; then an amount of air equal to that contained in the room will probably pass through it in an hour, and $\frac{1,700 \times 80}{12,500} = 11$

nearly, which added to 32 gives 43 square feet as the amount of radiating surface required in this case, where there is no special ventilation. This is equivalent to adding one-third to the radiating surface to provide for leakage, and in this case gives about 1 square foot of radiating surface to 40 cubic feet of space. Now, let us suppose that the room is to be ventilated at the rate of 6,000 cubic feet per hour, that is, that the air in the room is to be changed over three times an hour to provide for its constant occupancy by two persons. Then $\frac{6,000 \times 80}{12,500} = 38.4$, which added to 32 gives, in round numbers, 70 square feet of radiating surface required. In this case the incoming cold air would probably be admitted through the radiators, which would be arranged on either the indirect or the direct-indirect systems. It will be seen, therefore, that to heat a room by the indirect system, which necessitates ventilation, requires nearly twice the amount of the radiating surface which would answer if the room was heated by direct radiators only, with no change of air except that due to leakage.

As another example, let us take a 24-bed ward in a brick hospital located where a temperature of 20 degrees below zero is to be provided for, the internal temperature to be 70° F. We will assume that this ward contains 24,000 cubic feet, that it has 288 square feet of window-glass surface and 241 square yards of external-wall surface, and that under ordinary circumstances the supply of air is to be 3,600 cubic feet of air per hour per bed, or a total of 86,400 cubic feet of air per hour. To supply the loss of heat through walls and windows, we shall need $\frac{90}{140} \times (288 + 241) = 0.643 \times 529 = 340$ square feet of radiating surface. To heat 86,400 cubic feet of air from 20° F. to 70° F. would require $\frac{86,400 \times 90}{12,500} = 622$ square feet of radiating surface. Theoretically, then, $340 + 622 = 962$ square feet of radiating surface would be required to keep this ward thoroughly heated and ventilated in the coldest weather, which would be at the rate of 1 square foot of radiating surface to 25 cubic feet of space heated. Practically, it would be unnecessary to provide so much as this, partly because the heated air will supply part of the loss by walls and windows, partly because in such a climate, such a building would have hollow walls and double windows, which would much lessen the loss of heat, and partly because when the external temperature fell below zero a less amount of air supply would give sufficient ventilation for the comparatively short

periods of such extreme cold. About 700 square feet of radiating surface on the direct-indirect system would be sufficient for such a ward if properly distributed beneath the windows.

The writer of a series of articles on hot-water heating, recently published in the *Builder*, says that the best mode of calculating the heating surface required is to base it on cubic contents, and that the allowing so many cubic feet of air per person is objectionable because the number of persons has no relation to the size of the apartment since a small lecture room might have 200 people in it while a private reception room might be nearly as large and yet not have more than 20 occupants. Even calculations based on wall and window surface, he thinks, are not so good as those based on cubic contents. If instruction of this kind is given in such a journal as the *Builder*, it is no wonder that the ventilation of buildings is bad. The fact is, that the number of persons which the room is intended to accommodate determines the amount of air which is to be supplied, and the amount of air to be supplied in cold weather is a predominating factor in determining the amount of heat, and therefore the amount of heating surface required; while next to this in importance comes the amount of wall and window surface and relative exposure to winds, the cubic contents being of least importance of all in the great majority of cases.

The table given by the above-mentioned writer is of interest as indicating present English practice in hot-water heating. It assumes that the temperature of the water in the pipes is 180° F., that the lowest external temperature is 20° F., and that a foot length of 4-inch pipe gives 1 square foot of surface.

It will be observed that the temperatures specified for living rooms are lower than those required in the United States, that the assumed lowest temperature of the external air is at least 20 degrees higher than that usually taken as a basis of calculation in this country, and that the size of pipe is an inch larger than that ordinarily used for indirect hot-water heaters here.

When the schedule of rooms has been filled out so as to show for each room the amount of radiating surface which is to be provided, and its character—*i. e.*, whether direct, indirect or direct-indirect, including also the surface of coils for accelerating air currents in flues, if such are to be used, the next step is to indicate upon the floor plans the position of each of the radiators, and its size, as a basis for fixing the size and position of the pipes by means of which they are to be connected with the boiler so as to insure circulation. The location of direct radiators in a room must be governed mainly by the uses of the room and the

position of articles of furniture in it. So far as the heating of the room is concerned it is a little better that the radiator should be near the outer wall, especially if this is to be the windward side of the house in cold weather; but for most rooms the precise location does not matter much so far as warmth is concerned, and other things being equal, it may be arranged to suit connections with mains and risers so that these shall be short lines and with proper grades. Direct-indirect radiators will usually be placed beneath the windows. The indirect radiators will usually be placed in the basement or cellar, and may be divided into two classes, those placed immediately beneath the rooms to be heated, and those placed at a distance and requiring mechanical power to control the movement of air through them. The most usual arrangement is to place them just below the rooms to be heated and to have the

Temperature Required.	Quantity of 4-Inch Pipe Required for Every 1,000 Cubic Feet Capacity in a Brick-Built Room. Windows as Usual.	Some of the Uses for Which the Heat May be Required.
Deg. F.	Feet.	
50	6	Coach houses, etc.
55	7	Work rooms, etc.
60	8 to 9	Churches, bedrooms
65	10	Living rooms.
70	35	Drying room, herbs, paper, etc.
75	45	Free ventilation.
80	60	This heat when empty and dry.
100	110	Drying rooms for moist articles, laundry work, etc.
110	140	Full ventilation.
120	180	This heat when empty and dry.

flues leading from them constructed in the outer wall. To insure good results each room should have its own flue, its own radiator, and its own separate fresh-air supply for that radiator, but it is often difficult and somewhat expensive to secure this. If there are three or more stories to be supplied, and the rooms are not large, there may be some little trouble in getting the requisite number of flues in the wall, and still more trouble in getting separate radiators for each flue. Many men in planning for indirect radiation will give one common radiator for three or four flues and attempt to check the tendency of the flue going to the upper story to take more than its fair share of air by putting a diaphragm at its mouth or "throttling" it. In good work this taking of flues from the same radiator for rooms on different stories

should never be done, and it is never necessary to do it. The openings of the flues may be close together, separated by but a single brick, so that one or both of the radiators must be set back and connected with the flue by a duct of galvanized iron leading from its case; but while this increases the cost a little, it should be insisted on by the heating engineer and by the architect.

Having decided approximately on the location and size of the radiators, the next thing to be considered is the location and size of the mains and boiler. For all dwelling houses, and for the majority of buildings, a low-pressure apparatus, the condensed water from which returns to the boiler by gravity without the use of pumps is what is most frequently used. By a low-pressure apparatus is meant one which will give a circulation of steam throughout with a pressure of not to exceed one pound per square inch above the atmospheric pressure at the boiler and the maximum pressure in the boiler of which shall never exceed 10 pounds. To secure this sufficiently large supply and return pipes are essential, and to secure the gravity return the boiler must be set so far below the level of all the radiators as to permit the return of the condensed water by the return pipes sloping constantly towards the boiler with an easy grade. To prevent snapping and crackling noises within the pipes it is desirable that their grade should be such that the condensed water will always flow in the same direction as the current of steam; hence the supply mains should rise as soon as possible after leaving the boiler to the highest point to which it is necessary to carry them, and from this point should begin to fall to the most distant point at which connection is to be made with the return pipe, which from thence is to slope towards the boiler. In large pieces of work it is often impossible to arrange the pipes in this way and then it becomes necessary to use traps and perhaps, also, a pump or pumps.

There are many kinds of steam-heating boilers in the market and new patterns are being added every year. For all steam-heating plants requiring 1,500 or more square feet of radiating surface, none of them are superior to the ordinary horizontal flue boiler. For smaller plants, and under circumstances where horizontal space for the boiler is limited, it may be better to use some form of vertical boiler with drop tubes.

The size of the boiler required is fixed by the amount of radiating surface to be supplied, care being taken that it is in excess rather than too small. In localities where the external temperature may at times be 20° below zero F., as in Canada and the northern part of the United States, a square foot of heating surface in the boiler will be required to

each 5 square feet of radiating surface to provide for all emergencies. Where the external temperature is never below zero F., 1 to 6 or 6½ is sufficient. The proportion of grate surface to boiler surface varies greatly in different boilers, from 1 to 25 to 1 to 50 or more.

The size of boilers is often stated by bidders and contractors as being of so many horse-power, but this is an indefinite and unsatisfactory mode of stating it. What is commonly understood by a horse-power is a force equal to 550 foot-pounds per second. The French horse-power is 75 kilogrammeters = 542 foot-pounds per second. The common English horse-power is that produced by the evaporation of a cubic foot of water to steam, or about 70,000 thermal units, but it has been defined as equal to the evaporation of 30 pounds of water from 212° F., which would only require about 29,000 thermal units. Mr. Mills estimates one horse-power as equal to the supply of heat to 90 square feet of radiating surface, or the giving off of a little over 10 cubic feet of steam per minute. On this basis an 11 horse-power boiler would be required for 1,000 square feet of radiating surface.

With regard to sizes of mains for low-pressure steam work, the usual practice is to allow 1-inch pipe for 100 square feet of radiating surface or less; 1½-inch, for from 100 to 225; 2-inch, from 225 to 450; 2½-inch, from 450 to 700; 3-inch, from 700 to 1,200; 3½-inch, from 1,200 to 1,500; 4-inch, from 1,500 to 1,900; 4½-inch, from 1,900 to 2,300; and 5-inch, from 2,300 to 2,800.

Mr. Baldwin's formula is that the diameter of the main in inches should equal one-tenth of the square root of the number of square feet of radiating surface which it is to supply. In calculating by this rule the regular commercial sizes of pipes should be remembered as increasing in diameter by half inches up to 5-inch pipe, and above that by inches up to 15 inches.

The formulæ for sizes of chimney flues in connection with boilers are given in Chapter VIII.

The only objection to having the steam mains somewhat larger than is necessary is the slightly increased cost of the pipe—they add nothing to the cost of running the apparatus. The pipes for return of condensed water may be a size or two smaller than the corresponding steam pipes.

For comparatively large steam-heating plants, what is sometimes called the hot-blast system is recommended by some engineers. In this all the heating surfaces are as far as possible brought together in a special chamber or duct and the cold air is forced or drawn over these surfaces by a fan or blower, after which it is distributed by ducts

and flues to the different rooms. This is economical as to piping, and if forced ventilation by fans is to be used is in some cases a good plan, especially for buildings which are to be occupied but a few hours at a time, such as churches, assembly halls and large office buildings. For buildings which are to be continuously occupied, and especially for hospitals, it is not so advantageous, because it is difficult to so regulate the temperature of the incoming air as to produce the differences in different rooms which are often desirable. It is true that by the use of properly arranged mixing valves with separate cold-air inlets at the bottom of each flue this objection might be greatly lessened, if not done away with. This system may also be combined with the having small radiators at the bottom of each flue, adjusted to produce an increase of temperature of not more than 20° F., the air being delivered to them from the central coils at a uniform temperature of about 55° F.

In dwelling houses, offices, hospitals, and the majority of inhabited rooms, in proportioning the heating surfaces no account is taken of the heat given off by the bodies of the occupants or by the means used for illumination. In rooms where a large number of people are to be gathered, and which are to be occupied at night with many gas lights, the additional amount of heat thus produced must be considered, not so much with reference to the amount of radiating surface to be provided, since this will at times be called upon to do its work in the day time and when the room is nearly empty, as with reference to the means of cutting off a part of this radiating surface or of admitting more cold air, or both, when the room is crowded and lighted. This applies to assembly halls, school rooms, churches, theaters and opera houses, etc.

The heat produced by an ordinary candle is 100 calories per hour; that from an ordinary gas burner is 1,430 calories per hour; one gas burner using about 5 cubic feet of gas per hour requires 60 cubic feet of air for combustion.

The exhaust steam from an engine can often be usefully employed for heating purposes. For this purpose a back-pressure valve is placed in the exhaust pipe, and a pipe is taken from below this valve through a grease separator to the main supplying the radiators. These must be arranged for a low-pressure system, and the return must go to a tank from which the condensed water can be pumped by a special pump into the boiler if so desired. Usually a direct live-steam connection between the boiler and the heating system will also be required to provide for heating when the engine is not at work.

Where there are large boiler and engine plants, as at central electric light stations, this use of the exhaust steam to supply heat to neighboring buildings may be an important matter.

There are many patterns of radiators in the market and the number is added to every year. Each firm engaged in the construction of heating apparatus usually has its own favorite form, and architects commonly do not undertake to prescribe the particular pattern to be used, either leaving the heating contractor to make his own selection, or directing that the radiators shall be of such a pattern or its equivalent. We do not propose to discuss the merits of different forms of heaters for indirect work, or of radiators properly so-called. Those who wish detailed information on this subject will find the best data in the second volume of the valuable work of John H. Mills on "Heat: Science and Philosophy of Its Production and Application to the Warming and Ventilation of Buildings, etc," Boston, 1890, in which the results of a number of experiments made by Mr. Baldwin, Mr. Mills and others are fully stated. In selecting radiators, or in examining a completed piece of work to determine whether the required amount of radiating surface has or has not been furnished, it should be remembered that the number of square feet of such surface as stated by the manufacturer for a particular form of radiator, and known as the commercial rating, is often in excess of the true figure by from 10 to 25 per cent.

For heating of air, as by the so-called indirect or direct-indirect radiation, the object is to bring the cold air in at the base, force it to come in contact with the hot surface and allow it to escape at the top. The heating is therefore not effected by radiation but by conduction, and the arrangement of the heating surfaces calculated to produce the best result is altogether different from that which is best for true or direct radiation. Hence, for these indirect heaters, the value of an extended surface obtained by projecting knobs or pins, as in the well-known Gold's pin radiator, or by winding the pipes with wire, is great, while for direct radiators it is comparatively small.

Figure 24 shows one way of bringing in the air to the base of a direct-indirect radiator. The opening of the fresh-air duct *D*, is regulated by a damper, and when this is closed the apparatus becomes a direct radiator.

Such closure often becomes absolutely necessary when the direction of the wind is such that the radiator is on the leeward side of the building, to prevent the passage of air from the room outward through what is intended to be the inlet duct.

Figure 25 shows a form of radiator intended to allow the admission of cold fresh air at all times without giving rise to the danger of freezing water which may have accumulated in the bottom through leakage or improper setting of the valves. This was devised by Mr. Baldwin for the Moses Taylor Hospital, and the principle may be applied to any vertical radiator.

Immediately above each ordinary vertical tube of the radiator is a short tube *a*, through which the warm air from the steam tube must pass to escape through the fretwork at the top. The warm air, in

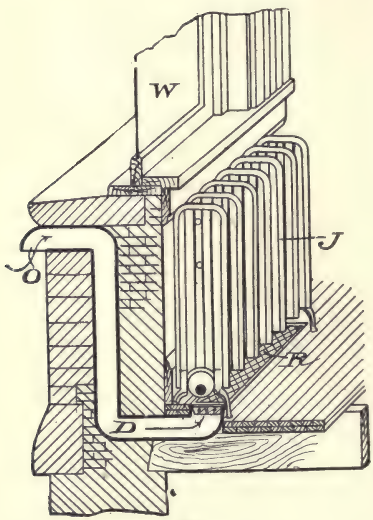


FIG. 24.

passing through the tubes *a* (which tubes may be of any desired length), warms them to from 120° to 140° F. The entering cold air, as indicated by the arrows, passes between these tubes and beneath the plate *b* to the front half of the radiator before it can mingle with the air from the steam-heated pipes. A plate similar to *b*, and extending over the whole size of the radiator, confines the lower ends of the pipes *a*, and prevents the entering air from falling among the steam pipes. In the front of the entablature, as shown by the plan, the tubes *a* terminate at the level of the plate *b*, and about three-quarters of an inch below the fretwork. This permits the air that comes through the tube (warm), and the air that passes between the plates

and the pipes *a* (slightly warm), to mingle as they pass through the fretwork, and prevents the ingress of air that is cold into the room. It is also claimed that a reversion of the current, whereby the warm air may pass out of doors, cannot exist.

In specifying a particular patented form of radiator, or one made by and obtainable from one firm only, it should be borne in mind that

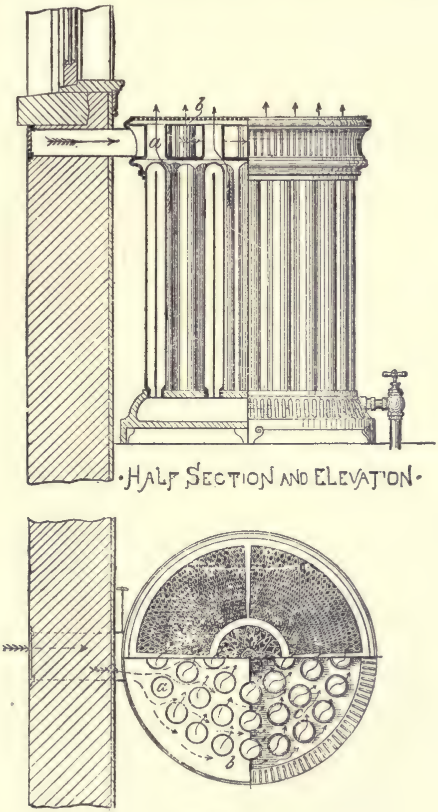


FIG. 25.

10 or 15 years hence it may be very difficult to obtain these radiators, or parts of them, for purposes of alteration or repairs. It is not in accordance with the best interests of the owner of the plant—though it may be good for the radiator trade—that he should be thus limited

in his future work, and the safest thing for him is to use radiators constructed of ordinary cast or wrought-iron pipe, of which there always are, and probably will continue to be, standard sizes in the market.

HEATING BY HOT WATER.

The advantages and disadvantages of hot-water heating apparatus have been in part indicated above. The use of water as a vehicle for the conveyance or storage of heat has long been known, but until recently it has been comparatively little used in this country, except for heating greenhouses, where the constancy and regularity of the heat, which it produces with comparatively little attendance, are of special importance. It is used in some of the large Government buildings and in the Johns Hopkins Hospital in Baltimore, and recently is being more employed for the better class of dwelling houses. The rules given above for scheduling rooms, etc., apply also to the preparation of plans and specifications for hot-water heating, but the calculation of the amount of radiating surface required is based upon somewhat different formulæ,

In heating by a low-pressure hot-water system the average maximum temperature of the water may be taken as 140° F., so that the radiating surfaces will be about 70° F. lower than those which are heated by steam, and hence must be increased proportionately. In hot-water heating the greater part of the work is usually done by indirect radiation, and the calculations are to be made with reference to air supply primarily, with secondary corrections for loss of heat by radiations from windows and walls. There are various forms of radiators for hot water, as there are for steam, but coils of 3-inch cast-iron pipe are as good as any other for indirect radiators, and give a convenient basis for calculation, since, including sockets, etc., 100 feet run of 3-inch pipe give about 100 square feet of radiating surface. Mr. Charles Hood, who is the chief English authority on hot-water heating, bases most of his calculations upon radiation from 4-inch cast-iron pipe, but the smaller size is preferred in this country because it has a larger radiating surface in proportion to the amount of water contained, and therefore insures a quicker circulation. It will not do to use less than 3-inch pipes in most of the radiators, because the friction increases rapidly with the reduction of the diameter of the pipe, and thus impedes the circulation and diminishes the effect. Where it is specially important to guard against the effects of negligence in firing, as in a greenhouse, and where, therefore, a large body of hot water is needed

as a sort of storehouse of heat, 4-inch pipes may be usefully employed, but not otherwise.

Mr. Hood's calculations as to the amount of air to be warmed are based on a supply of from 3½ to 5 cubic feet per minute for each person in habitable rooms, which is hardly one-tenth of the amount required for the preservation of health and comfort. He also allows 1¼ cubic feet of air per minute for each square foot of glass which the building contains, and having thus calculated the quantity of air to be heated per minute, he gives the following rule for finding the amount of pipe required to heat it :

"*Rule.*—Multiply 125 by the difference between the temperature at which the room is purposed to be kept when at its maximum, and the temperature of the external air, and divide this product by the difference between the temperature of the pipes and proposed temperature of the room, then the quotient thus obtained, when multiplied by the number of cubic feet of air to be warmed per minute and this product divided by 222, will give the number of feet in length of pipe, 4 inches diameter, which will produce the desired effect."

This rule depends upon the fact, determined by experiment, that 1 foot of 4-inch pipe will heat 222 cubic of air 1 degree per minute, when the difference between the temperature of the pipe and the air is 125 degrees. To apply it to 3-inch pipe, the quantity should be increased by one-third.

From this it would follow that to heat 1,000 cubic feet of air per minute, using for this purpose 3-inch pipe at the temperature of 180° F., and supposing the temperature of the external air to be at zero F., there would be required to maintain the room at the following temperatures, the amount of pipe set underneath each—viz.:

Temperature at which room is to be kept....	55°	60°	65°	70°	75°
Number of feet of 3-inch pipe required for each 1,000 feet of air per minute supplied.	330	375	424	477	536

Those who furnish hot-water apparatus very rarely calculate the amount of radiating surface with reference to the amount of air to be supplied. They proportion the amount of radiating surface to the cubic space to be heated, according to certain empirical formulæ, in which usually the question of ventilation is not taken into account.

For example, to heat churches and large public rooms, Hood allows 1 foot of 4-inch pipe to each 200 cubic feet of space; that is, 5 feet per

1,000 cubic feet. For dwellings he allows 14 feet per 1,000; for schools and lecture rooms, from 6 to 7 feet, and for greenhouses 35 feet per 1,000, and says that these amounts have been determined by actual trial.

Mr Anderson, in a valuable paper on the emission of heat by hot-water pipes, concludes that for ordinary dwelling houses, 1 square foot of surface is necessary to every 65 cubic feet, and in a greenhouse 1 square foot to every 24 cubic feet. These figures are based on data collected by him, a specimen of which is given in the accompanying table.

There is, however, one very important defect in the table—viz., it gives us no information as to the amount of air which passed over the heating surface in a given time. In the school buildings there seems to have been no ventilation at all. It does not seem to have occurred to Mr. Anderson that ventilation is of any importance in connection with heating problems. He remarks that "the heating surface necessary to warm a given building depends on a variety of circumstances—on geographical position, whether the house stands high and exposed or low and sheltered, and whether the average winter temperature is high or low; on the thickness and material of walls; on the area and construction of windows, and so forth." All this is true so far as it goes, but the ventilation is more important than any of the points he has named, and it is curious to see how totally he ignores it.

For American climates and for details of apparatus the best book on this subject is "Hot-Water Heating and Fitting," by W. J. Baldwin, New York. *The Engineering Record*, 1889. As explained above, the technical difficulties to be overcome are greater in the case of hot-water than of steam apparatus, and require greater care in proportioning areas of pipes and openings, in maintaining proper grades, etc., in order to secure the requisite amount of circulation in every part of the apparatus, but with a good system the results are very satisfactory.

The provision of automatic means for regulating a heating apparatus so as to maintain substantially the same temperature in a room or building is sometimes desirable. There are several means of doing this, some directly mechanical by the expansion or contraction of a strip of metal, and others acting by production of an electric current by contact. An old form is Appold's apparatus, shown in Fig. 26.*

* Gassiot (J. P.) on Appold's apparatus for regulating temperature and keeping the air in a building at any desired degree of moisture, in Proceedings, Royal Society of London, 1866–67, Vol. XV., pp. 144–5.

Description of Building or Room.	Approximate Working Temperature of Pipes.	Cubic Feet of Air Contained.	External Cubic Capacity.	Area of Heating Surface.	Cubic Feet to 1 Square Foot of Heating Surface.		Cubic Feet of Air to 1 Square Foot of Heating Surface Reduced to 160°.	Area of Walls and Ceilings.	Number of Square Feet of Wall Surface to 1 Square Foot of Heating.	Area of Windows.	Remarks.
					Air.	Total External Capacity.					
LESNEY HOUSE, ERITH, KENT.	°			sq. ft.				sq. ft.		sq. ft.	
The whole house is warmed by hot water, more especially the passages, which in the coldest weather can be maintained at 60 degrees. The rooms all open into the passages. The house stands 150 feet above the river, and is much exposed.											
STUDY.—Bow window to the east. Hot-water pipes under window seats, with three openings 7"x4½", covered by perforated zinc, through the walls to admit external air through coils. Coils concealed by open cast-iron work; constant current up the chimney. Only one external wall, namely, the bow window...	160	3,329	....	83.0	40.0	...	40.0	1,098	13.2	96	Excess of heating power.
DINING ROOM.—Bow window, facing to the north, with coils in all respects as in the study. Another window faces to the west. Two external walls...	"	5,386	...	83.0	65.0	...	6.50	1,481	17.8	118	Sufficient heating power.
BATH ROOM.—One window, facing west; group of pipes placed against inner wall opposite window; no communication with the external air; open chimney; one external wall...	"	1,072	...	53.3	20.1	.....	20.1	525	9.9	18	Great excess of heating power.
ERITH PUBLIC ELEMENTARY SCHOOLS.											
One-story brick buildings, not plastered inside, stand near the river, and sheltered by surrounding houses, the roofs ceiled up to the collar tie. The coils of pipe are quite open, and placed near the walls, most of which are external:											Only just heating surface enough.
Boys' school...	"	24,917	29,465	326.0	76.4	90.4	76.0	5,213	16.0	342	Hardly sufficient heating power.
Girls' school...	"	26,257	32,890	325.0	80.8	101.5	80.8	4,409	13.6	312	Insufficiently heated.
Infants' school, total...	"	37,195	41,350	442.0	84.1	93.8	84.1	5,198	11.7		These rooms are too cold for the comfort of the children.
Class rooms—A...	"	5,206	"	51.0	102.0	"	102.0	830	16.2	432	
" " B...	"	4,932	"	50.0	98.6	"	98.6	830	16.6		
" " Babies' south aspect...	"	6,544	"	83.0	78.8	"	78.8	1,230	14.8		Barely sufficiently heated

This instrument consists of a glass tube having bulbs at each end. The tube is filled, as also about half of each bulb, with mercury, the lower bulb containing ether to the depth of half an inch, which floats on the mercury. The tube is secured to a plate of boxwood, and supported on knife edges, on which it turns freely. At the end of the plate, underneath the highest bulb, is a lever to which a string is attached. This string is carried, by means of bell cranks, to the supply valve of a gas stove or the damper of a furnace.

The instrument acts in the following manner: Supposing the stove to be lighted and to have raised the temperature more than is

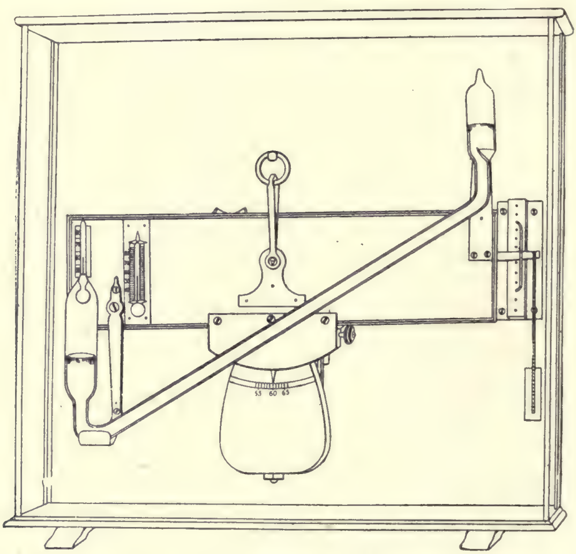


FIG. 26.

required, the heat will convert a portion of the ether in the lower bulb into vapor. The expansion of this vapor drives a quantity of the mercury out of the bulb underneath it through the tube into the upper bulb. The end to which the mercury has been driven being thus rendered the heaviest, falls, and motion being communicated by the lever to the string, this closes the supply valve or damper of the stove or furnace. Of course, if this should be carried beyond the required extent the reverse action will take place.

A weight in the center of the plate, the position of which is regulated by a milled-head screw shown at the side, serves to alter the center of gravity of the whole apparatus. The value of the motion of this weight being carefully ascertained, a scale is engraved upon it. By moving this weight, according to a scale engraved on it, the instrument may be set so as to maintain any desired temperature in the building in which it is fixed.

The range of action of the instrument is from 54° to 66° F., and with a change of temperature of 1 degree it has the power to raise one ounce 3 inches.

Of thermostats for controlling heating by means of electricity there are several kinds in the market. One of these, operating by means of compressed air, is shown in Fig. 27 as applied in the Mechanics Bank Building, in New York, and described in *The Engineering Record* of August 9, 1890.

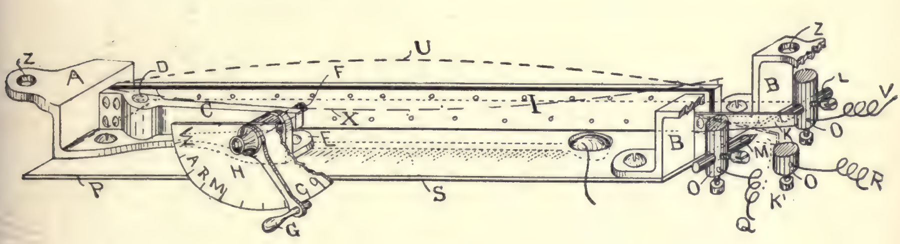


FIG. 27.

This thermostat may be set to work at any temperature, and is claimed to operate satisfactorily within a range of 1 degree. The figure shows the back of the instrument that is mounted on a brass bed plate *P*, to which are fixed the standards *A B B* that carry the mechanism and have holes *Z Z* for attaching it to the wall or other convenient support. One end of lever *C* is connected to *A* by the pivot *D*, and the other end by a screw *F* tapped through lug *E*.

The expansion bar *I* is made of a plate of brass and a plate of rubber riveted together and attached to lever *C* at pivot *D*.

The other end of the bar is free and carries a platinum contact bar *K*. *O O O* are bind posts fixed on plate *B*, and receiving the circuit wires *Q R V*, and the adjustable contact points *L* and *M*. The rubber and brass in bar *I* expand and contract differently for the same differences of temperature, so that a rise in temperature will make it

bow out to the (exaggerated) position U, and throw K to K' in contact with M, thus completing the electric circuit from R through Q and opening the valve.

A fall in the temperature bows out I in the opposite direction to the (exaggerated) position X and makes contact between K and L, thus completing the circuit from R to V and closing the valve.

By moving lever G along the scale H, screw F is turned and swings lever C on its pivot D so as to set the bar K nearer to either L or M, and make the thermostat operate at any desired temperature within 15 degrees of that originally provided for.

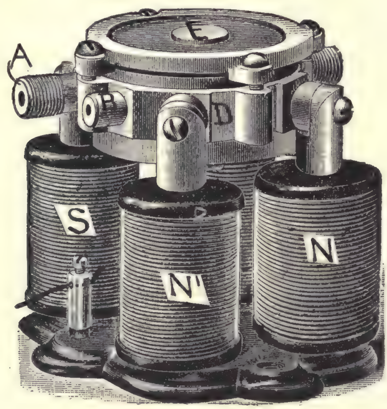


FIG. 28.

T is a thermometer with scale S on the face of plate P; the thermometer is entirely independent of the thermostat and in no way connected with its operation, but is attached to it simply for convenience.

The current from the thermostat operates the electro-pneumatic valve, of which Fig. 28 is a general view and Fig. 29 is a plan with the top E removed.

The chamber D is substantially a three-way valve with its ports opened and closed by a pair of electro-magnets. A, C and B are tubes to the compressed-air main, to the steam valve, and a free vent, respectively. C is always open into chamber D. A is open when B is closed and *vice versa*. N S and N' S' are electro-magnets. J J are armatures connected by cross-piece K that is pivoted in the center.

Lever G, pivoted at the center, has its faces F F covered with rubber, into which the sharp edges of tubes A and B sink and make tight joints.

The arm I is pivoted to one end of armature J and carries the contact roller H that has its bearing on G maintained by the spiral spring O. The operation by the thermostat, Fig. 29, is as follows: Air pressure is always maintained in tube A; suppose it to be shut off as shown in Fig. 29, then the vent B is open and the steam valve operated through pipe C is open; if now the temperature rises a little and

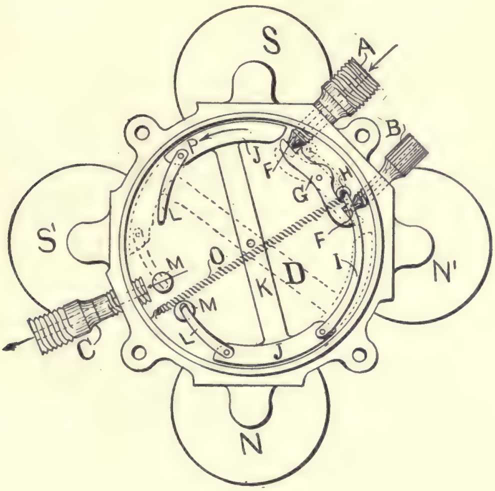


FIG. 29.

operates the thermostat it sends a current through V and magnetizes the poles N' S', which then attract the armatures J J that revolve in the direction P, and the movable parts of the mechanism take the positions shown by dotted lines; lever G opens A and closes B, and the pneumatic pressure in C closes the steam valve. When the temperature has fallen sufficiently the thermostat changes the current from V (Fig. 27) to Q, which correspondingly cuts it off from electro-magnet N' S', Fig. 29, and sends it through electro-magnet N S, which then attracts the armatures J J back to the original position, shutting off air pressure through A, opening vent B and allowing the steam valve to open as pressure fails in C. L L are contact springs that switch off the

current through conductors *M M* as soon as the armatures reach their extreme positions, thus cutting off the current and saving the battery.

Figure 30 is a sectional view of the steam valve and shows its operation by compressed air from tube *C*, Fig. 29. *F* is the steam inlet, and *Q* its outlet. *B* is the valve seat and *A* the poppet valve, whose stem passes through a stuffing box *E* and is fastened to a wooden head *H*.

I is a circular rubber diaphragm, clamped between the hemispherical shell *J* and the ring *K*. *L* is a spiral spring that opens the valve *A* as shown, when there is no pressure in chamber *M*; if press-

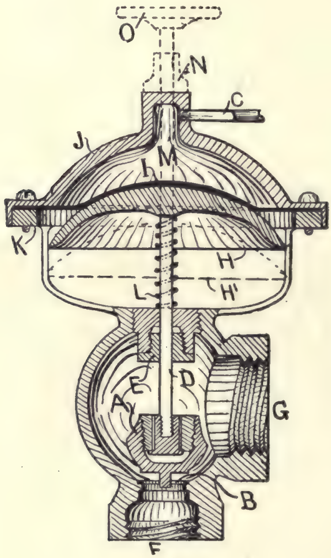


FIG. 30.

ure be admitted through *C*, the diaphragm and stem head will be forced down towards position *H'*, indicated by dotted lines, and the valve will be closed and steam shut off as long as pressure is maintained in *M*. This cut shows the valves as used in this case, but in some cases the stem *D* is continued to pass through another stuffing box *N* and terminate in a handle *O*, shown by dotted lines, so as to admit of regulation by hand at the radiator independently of the thermostat system.

Globe valves, gate valves and other forms are also arranged in the same manner.

CHAPTER XI.

SOURCES OF AIR SUPPLY. FILTRATION OF AIR. FRESH-AIR FLUES AND INLETS. BY-PASSES.

IN selecting the point or points from which the external air is to be taken for purposes of ventilation, it is usual to consider only the character, position and relations of the heating apparatus. In warm weather it is presumed that windows, and often doors will be opened, and that the air in the immediate vicinity of the building, whatever may be its impurities, will be admitted freely. The same is the case in cold weather, in heating by direct or by direct-indirect radiation; whatever air is admitted comes from the immediate exterior of the building.

In heating by indirect radiation the air may be taken in the same way from near the ground in the immediate vicinity of the furnace or of each separate heater, or it may be taken from a point, more or less elevated and more or less distant from the building, with a view to obtaining the purest air possible. The great objection to taking the air from near the surface of the ground is that it is more liable to contain dust, especially when the openings are directly on the street through a basement window, as is very commonly the case in cities. Where the openings are over a grassed surface or lawn, as is the case in the Johns Hopkins Hospital wards, there are no special objections to such a location.

If a special single inlet for air for a large building is to be provided in connection with some form of blower or aspiration system, it may be taken down through a shaft or tower between 20 and 30 feet in height. Above this height the air in a city is liable to be contaminated by smoke and fumes of various kinds, and in any case a height of 25 feet will probably reach as pure a stratum of air as can be found in the vicinity. A good example of such air-inlet towers is found at the Capitol, at Washington, where one is provided for each wing.

In connection with the inlets we are sometimes called on to provide for the removal of particles of soot and dust of various kinds suspended in the air, or, in other words, for the filtration of the air. So far as healthy persons are concerned, this matter of air filtration is a point

of theoretical interest rather than of practical value, and if we can give to such persons a sufficient supply of such air as they will breathe when walking in the street, we shall have done quite as much as will usually be required.

In buildings or rooms containing sick persons, or works of art, books in fine bindings, or other things to which dust will be injurious, and for chemical and bacteriological laboratories, it will be well to provide means of removing the dust from the incoming air. If the building be heated by any form of indirect radiation, and the air supply for this purpose enters through a single duct, this can be easily done by using strainers of coarse cotton cloth or of thin layers of cotton batting inclosed in wire frames. The chief points to be borne in mind in arranging such a system of filters are, first, that they form a decided obstacle to the entrance of air, as they give rise to much friction, and hence, that their area must be six or eight times that of the delivery flues; and second, that the filters must be renewed as often as they become clogged and foul.

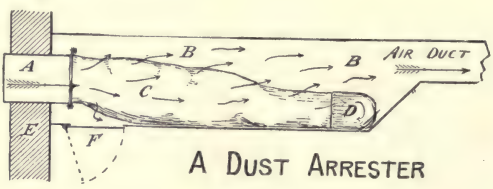


FIG. 31.

One mode of arranging such a filter is shown in the accompanying cut taken from *The Engineering Record* of April 13, 1889. It consists of a long muslin bag placed in an enlarged end of the air duct. *A* is the air inlet through the wall of the building and *C* is a bag—as long as possible and made tapering—with an end of canvas *D*, to catch and hold the accumulated dust and dirt. *B* is the enlarged part of the air duct to contain the bag, and a door should be provided at *F* for the purpose of removing the bag when foul and putting in a clean one. The bag should be turned inside out and washed and dried before using again, and two or more bags should be provided so as to have a clean one always ready. The longer the bag is the better, and if at first it seems to be a little longer than necessary, from the fact that it is not at once fully inflated, the inflation will increase as the muslin becomes more and more clogged with dirt, and a similar effect will be noticed in damp weather. New bags should be well washed before

using, so as to remove any size or stiffening that there may be in the cloth.

Figure 32 shows the arrangement of the radiators placed beneath the windows in the Laboratory of Hygiene of the University of Pennsylvania, where it is specially desirable to remove the dust from the incoming air; *A A*, fresh-air opening in wall beneath windows, covered externally with a wire screen; *D*, valve which controls this opening; *R*, radiator; *R B* tin-lined box surrounding radiator; *T*, door in front of box which, when raised, permits the air in the room to circulate through the radiator as shown by the arrows *X X*; *y*, the filtering screen composed of cheese cloth held in place by wire gratings.

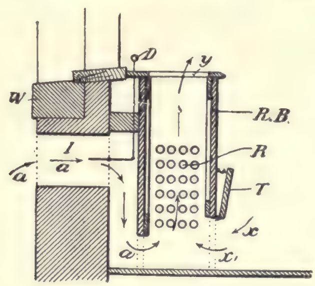


FIG. 32.

In public buildings attempts are sometimes made to accomplish this filtration, as well as to secure moisture and coolness, by passing the air through sprays or thin sheets of water. Where it is desirable to filter the air for a single room, as, for instance, in a case of sickness, this can be done by placing a large frame before the register, covered with two or three layers of coarse cotton cloth. Slices of coarse sponge have also been recommended for this purpose, but they obstruct the air too much. If the sponge be moistened and hung in front of the register it will act to some extent as a filter, but mainly as a source of moisture to the air, and as a means of lowering its temperature by the rapid evaporation produced.

In living rooms, heated by a hot-air furnace or by indirect radiation by steam, the use of a large, coarse, moist sponge in front of the register will often be a source of great comfort. Vessels of porous clay, through which water percolates rapidly, are used for the same purpose.

In the Glasgow Infirmary the air is filtered and washed by being passed through a screen 16 feet long and 12 feet high, formed of

cords of horse hair and hemp closely wound over top and bottom rails, which screen is kept constantly moist by trickling water so that dust and soot particles which have adhered to it cannot be removed by air currents. By means of an automatic flush tank 20 gallons of water are discharged over the surface of the screen every hour to wash off the accumulated particles. By means of aspirating fans the air is drawn through this screen at the rate of about 1,000 cubic feet per hour for each square foot of surface, and it is said to effectually remove all soot and fog.

The advantage of dry filtration of incoming air is that it causes much less obstruction to the current than a wet screen, and consequently requires less area. The disadvantage is that it must be frequently changed—while by the use of a spray screen or a wet screen flushed at intervals, the dust particles are washed away. The objection sometimes urged against dry screens that they collect germs which may afterwards be given off to the air currents is of small importance, for the number of pathogenic micro-organisms in the free air is very small, and so far as these are concerned it is not worth while to attempt to free the external air from them; the chief use of the filter screen is to remove particles of soot, pulverized straw, horse dung, etc., which make up the greater part of ordinary street dusts.

The fact that at a certain moderate depth the temperature of the earth is found to be uniform at all seasons has long been known, and a number of proposals have been made to utilize this in heating and ventilation. In his work on the British Army in India, published in 1858, Dr. Jeffreys mentions an attempt made in 1824 to ventilate with cool air a large hospital at Cawnpore, India, by means of a long and large tunnel, which, he says, failed because the cooling surface and the depth were insufficient.

In another part of the same work he proposes to ventilate the soldiers' barracks in India by making use of this principle, saying that "we may view the uppermost 50 feet of the earth's surface—or as many feet down as we can reach without the intrusion of water—as one vast equalizing reservoir, ready to absorb, from any amount of air we may choose to subject to its action, a large proportion of its summer heat, even if we do not aid our reservoir in its annual emptying itself of such heat in the cold season, but leave it to conduct back, spontaneously, such heat tardily upward to the surface during the winter months. But if we adopt proper measures for cooling thoroughly in the winter the mass of earth we select for our absorbing reservoir, we may have it emptied of more than the accumulated sum-

mer heat before the ensuing hot season, and brought down nearly to the *winter mean*, and ready, therefore, to absorb again much more heat than when it had to cool itself by the tardy spontaneous process of upward conduction through its whole mass.

"Now, if we select contiguous to a barrack of the largest size a plot of ground, *A*, *B*, *C*, *D*, Fig. 33, only 100 yards square, or 120 yards long by 80 yards wide—less might do—and prick it over with wells about 7 yards apart, the cost of digging them all will be only £20, and we shall possess 200 to operate upon a cubic block of earth 100 yards square* and, say, 50 feet deep. There are numerous parts of India in which, the water being 40 or 50 feet or more from the surface, dry wells to that depth may be dug; but, on the other hand, in many localities, as at Meerut, Bareilly and Delhi, the depth is much less, in some not half as much. In such places the number of the wells

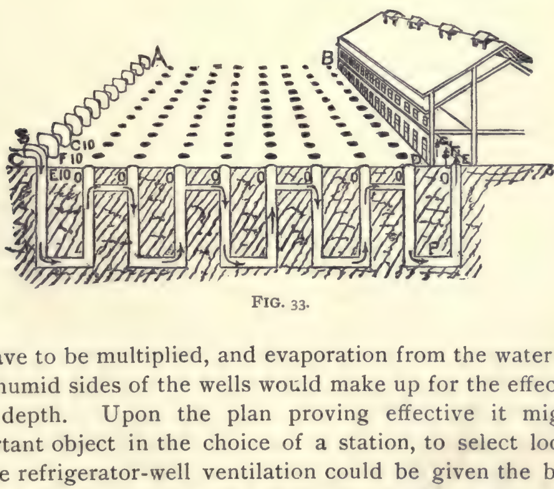


FIG. 33.

would have to be multiplied, and evaporation from the water's surface and the humid sides of the wells would make up for the effect of their inferior depth. Upon the plan proving effective it might form an important object in the choice of a station, to select localities in which the refrigerator-well ventilation could be given the best effect —whether with deep wells and a drier air, or with shallow and more humid.

"At Futtehgurh, Cawnpore, Agra, and in Bundelcund, etc., dry wells from 40 to 70 feet deep may be dug.

"To put the wells in action we may proceed thus: Let *E*, *F*, *G*, etc., be successive rows of wells; the first of each row, *E* 1, *F* 1, *G* 1, being sunk in the lower veranda of the barrack throughout its length,

* The plot of ground may, preferably, be oblong, as 200 yards by 50, according to the length of the barrack or barracks.

though this is not necessary, and the mouths of this row being covered with wooden or bamboo gratings to guard against accidents.

"All the wells exterior to the building, excepting the furthermost of each row, *E* 10, *F* 10, etc., must have their mouths closed and plugged for some feet down, by straw resting on a simple bamboo frame propped across the well, as at *O*, *O*, *O*, etc.

"If the ground is wanted for exercising the men, the mouths of the wells must be arched over with brickwork and covered level with the ground around ; but as this would be expensive, and the ground on one side of a barrack can generally be spared to that moderate extent, the simplest course would be to raise a common mud wall a foot or two high round each well, and to cover the straw, plugging its mouth with matting or a thin thatch. The earth dug from the wells would raise the level of the surface about a foot, and would in general yield, if the lower sand were not put uppermost, a fertile virgin soil.

"The whole area between the wells might form a productive garden, with its surface kept cool by frequent watering from a few wells reserved and deepened for the purpose, and by being covered with vegetation ; but it must not be such vegetation as could be a source of malaria. This use of the surface would appreciably check the traveling of heat downward into our cubic reservoir below.

"The wells of each row must be made to communicate with each other, thus : from the bottom of *E* 1, a horizontal passage *P*, about 2½ feet high and 15 or 18 inches wide, must be cut to the bottom of the next well of the row *E* 2, and from near the top of this well below the straw about 10 feet, beneath the surface of the earth, a similar horizontal passage must proceed to the next well *E* 3, and from the bottom of this well a passage to *E* 4, and so on to the last well *E* 10, according to the number of wells in the row.

"This last well being surmounted by a large cowl *S* (turned to the wind by a fan-tail or a lever moved by hand), and acting as a wind-sail, the wind will blow down it and through the passage at the bottom to the next well, then up it and through its upper passage to the third well, and pursuing this course through all the wells, will make its exit through the grating of the well *E* 1, and into the veranda *T*, which should be securely closed As in each row of wells the last would be similarly surmounted with a cowl, every first well of each row would pour forth air into the veranda."

I have given Dr. Jeffreys' description in full, because his book is somewat rare, and because the principle which he set forth has been made the subject of one or two comparatively recent patents, as

for instance, in that granted to Mr. John Wilkinson, July 29, 1879, for an improvement in tempering and purifying air and ventilating structures.

In 1876 Mr. Wilkinson published a pamphlet entitled, "How to construct a perfect dairy-room," etc., in which he gives plans for a dairy connected with a subterraneous duct about 200 feet long, through which the air supply is to be drawn, and since that time he has written a good deal for the daily press upon the merits of his patent sub-earth ventilation.

March 11, 1879, a patent was granted to Morrill A. Shepard for an improvement in producing heat and ventilation by sinking wells or shafts to reach a water-bearing stratum, in which are to be laid pipes through which the air supply for the building is to be drawn. As Mr. Shepard's object is to have his fresh-air supply pipes surrounded by water of nearly constant temperature, he would also have such pipes laid in rivers to supply adjacent cities.

The principle of sub-earth or water ventilation having been distinctly announced by Dr. Jeffreys in 1858, anyone is at liberty to make use of it, but it is only under special circumstances that it possesses any practical value. In cities it would be highly inadvisable to use subterannean passages as air-supply sources, because of the great risk of contamination of the air with deleterious or offensive gases. In the country there is less risk of this, but even there the percentage of carbonic acid in the air will be markedly increased by passing it through a sub-earth duct. This, however, will not injure it for dairy supply, and dairies constructed in accordance with this principle will be found very satisfactory as regards ventilation and temperature.

The force necessary to secure a movement of air for ventilating purposes can, of course, be obtained by the cooling of a column of air in a shaft as certainly as by heating it, the essential point being to produce a difference in the weight of equal volumes of air by giving them different temperatures, and then utilizing this difference in weight to produce a movement of air in the direction desired.

In the great majority of cases, however, it will be found much cheaper and simpler to do this by adding than it will by abstracting heat.

In the chapter on heating, attention has been called to the desirability, in arranging the heating and ventilation of a large building, of preparing schedules of the different rooms, showing for each the length, breadth and height, cubic capacity, area of windows and of external walls, exposure or frontage, purpose or use, number of occupants, amount of air supply, and amount of heating surface.

In order to do this methodically, the rooms on each floor should be numbered in regular order, and then scheduled, the floor being designated by letters of the alphabet. *B* 7, then, indicates room No. 7 on the second floor, and this mark can be placed on the plans on all flues connected with this room.

Having these data and the floor plans before us, the next step is to locate on the plans the position of inlets, outlets and flues, and to indicate their sizes. The area of the fresh-air registers or inlets will depend somewhat upon the location in the room at which the air is to be introduced, and this location must be determined by the following considerations :

First.—The register must be in such a position and of such size that the requisite amount of air can be introduced through it without causing currents of air of such velocity as will cause discomfort to the occupants of the room. The only difficulty in this respect occurs in rooms occupied by a number of persons, such as assembly and school-rooms, churches, theaters, hospitals, etc. Under such circumstances it is sometimes difficult to so locate the fresh-air inlets that the currents therefrom will not be unpleasantly perceptible if they are rapid, and it may then become necessary to make these inlets of such an area that the velocity of the inflowing air need not exceed 1½ feet per second to secure the introduction of an amount sufficient for both warming and ventilation. Bearing in mind the tendency of air to adhere to surfaces, it will almost always be possible, by the use of deflecting or baffling plates or screens, to direct the incoming current in such a manner that it will not cause draughts. In churches, theaters and assembly halls the fresh-air inlets should be so placed as to avoid interference with the acoustic properties of the room, as will be explained in the chapters treating of the ventilation of such buildings. When the registers are so situated that the currents from them will produce no discomfort they may be made smaller, provided that sufficient power is applied to make the current swifter. For example, if it be determined to introduce the fresh air directly through a perforated floor in an assembly room, the total area of openings should be at least 100 square inches for each occupant, while the area of register openings need not be more than 30 square inches for each occupant if they are placed near the ceiling, and a fan is used to ensure the requisite velocity.

Second.—Taking it for granted that the fresh air is to be warmed in cold weather before it is brought into the room, its registers must not be placed below the foul-air registers, unless the former are scattered

all over the floor of the room. The reason for this is, that direct currents between the inflow and outflow registers are easily established when the latter are above the former, and in such case little change is effected in the great mass of the air in the room.

Third.—Flues of proper size cannot usually be placed in thin walls, such as ordinary interior partitions. A flue measuring less than 5 inches in its smallest diameter is of little use. Fortunately, in ordinary dwelling houses, where this difficulty of thin partition walls is greatest, the precise location of fresh and foul-air flues is of minor importance so long as the precaution advised in the preceding section be observed.

Fourth.—Fresh-air registers should not be placed in a floor so as to be flush with its surface, because dust and dirt will fall into the flues and be returned to a certain extent in the column of ascending air. Such registers are also a fruitful source of loss of small articles. It is always possible to continue the flue upward into a step or seat, and then place the register in the side of this.

There is less objection to placing foul-air registers in the floor; but even this should be avoided unless the openings are covered by some article of furniture, as for instance, in a hospital ward, where a good position for the foul-air registers is in the floor beneath each bed; and even then the register should not be flush with the floor, but rise an inch or two above its surface.

Fifth.—In dwelling houses and buildings of moderate size it is economical to centralize the heating apparatus as much as possible, keeping the fresh-air flues in inner walls; but it is not easy by this method to secure sufficient warmth in the vicinity of windows, especially on the side most exposed to the winter winds.

On the other hand, hot-air flues should not be placed in outer walls, unless these are thick and substantial, and even then it will be good economy to make the flue of terra-cotta or galvanized iron, so set as to leave an air space of an inch or two on the outer side. For rooms on the floor immediately above the radiators, it is not necessary to place flues in the walls in order to bring the registers under or near the windows, which is their best place so far as heating is concerned. Foul-air flues should not be placed in outer walls, unless they are to be carried downward and to have some means of aspiration connected with them.

Sixth.—General Morin, and the majority of modern French engineers, advise that the place of introduction of fresh air shall be near the ceiling, in order to avoid unpleasant currents, while the discharge openings, on the contrary, should be near the floor. The introduction

of warm air near the ceiling, in order to prevent disagreeable currents, is not absolutely essential, for such currents can be avoided, as above explained, by making the registers of proper size; and to secure comfort in cold weather, it is necessary, on this plan, that the air shall be introduced at a temperature several degrees higher than is required if it be admitted at a lower level.

The proper position of the foul-air registers depends on the purpose of the room and on the season. During cold weather, in the majority of cases they should be near the level of the floor, to secure a satisfactory distribution of the air with the least expense. In large assembly halls, however, and especially where it is desired to provide for respiration-air as pure as possible instead of foul air diluted to a certain standard, the discharge openings should be above.

Seventh.—In order to secure a thorough distribution of the incoming air, it is usually recommended that the discharge openings should be in the side of the room opposite to that in which the fresh-air openings are placed, and as far as possible from them.

In all dwelling houses, however, and in rooms not having windows on opposite sides nor containing a sufficient number of occupants to exercise any special influence on the temperature, good ventilation will be secured by placing the fresh warm-air openings on an inner wall, and the discharge openings in the same wall at the same or a lower level. This is the arrangement in most dwellings heated by indirect radiation, the fresh-air register being in the side of the chimney near the floor, and the foul air passing out through perforated fireboards on the same level a few feet away. The result is the establishment of a circulation from the fresh-air opening upward and along the ceiling to the outer walls and windows, thence down the wall to the floor, and along the floor to the discharge.

But when we come to deal with rooms having a large floor-area in proportion to the height, and containing 50 or more persons, whose heat production is a factor that must be taken into consideration, there is some danger in this method that there will be an unsatisfactory distribution of the fresh air when the temperature of the external air is not below 50° F.

It has, however, been applied to school rooms with reported good success, and the reader is referred to the chapter on school houses for details.

Eighth.—Each room should have its own fresh or warm-air flue separate from all others. Two or more rooms above each other should never be supplied from one common flue.

The area of the inlet register should have a clear area of opening, exclusive of the iron grating work, from 20 to 25 per cent. larger than that of the flue which supplies it, if this flue be a small one. This is because of the considerable obstruction to the air current produced by the valves and the ornamental work in front of the register which not only diminish its effective area of opening but produce much friction. The size to be given to inlet and outlet flues depends on the quantity of air to be passed through them and the velocity permissible or obtainable. In estimating this velocity much depends upon whether the current is to be produced by differences of temperature only or by mechanical power as by a fan, but even when a fan is used the velocity should not be over 10 feet per second in the smaller flues or there will be great waste of power from friction. In inlet flues coming from the basement in case of heating by indirect radiation the velocity will increase with the length of the flue, other things being equal. In the flues leading to the first floor the velocity will usually not exceed 4 feet per second, while in those to the second floor 5 feet per second,

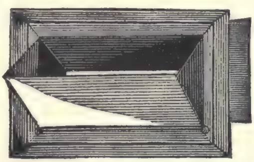


FIG. 34.

and to the third floor from 6 to 7 feet per second may be counted on when the external temperature is below 50° F. For the same reason the velocity in upcast foul-air flues is greater in those of the lower stories than it is in those of the upper.

With regard to inlets for fresh air to come in directly from without and not to pass through or over any heating apparatus, there are a variety of contrivances intended to give such a direction to the entering current that it shall become diffused and imperceptible by the time the air reaches the persons in the room and usually this is effected by giving the current an upward direction. As an example of this kind of inlet we may take the Sheringham valve which is much used in English barracks, but which in this country is chiefly employed in stables.

In this the air enters through perforated bricks or an opening covered with wire gauze or perforated zinc, and is then directed upward by a valve opening, the deflecting plate of which is so arranged

that it can be set at any angle or made to close the opening entirely. (Fig. 34.) The internal opening of these valves usually measures 9″x3″.

If the room is heated by indirect radiation such valves would in most cases become outlets. They are most useful in moderate weather and in rooms heated by direct radiation.

Another form of direct cold-air inlet consists of tubes entering the room at any convenient point above the floor level and then bent upwards so as to produce a vertical current like the jet of a fountain to which the ceiling of a room of ordinary height will act as a deflecting plate.

For dining rooms, smoking rooms, and reception and drawing rooms in dwelling houses, where it is desirable to make provision for the gathering of a considerable number of persons with extra lights, on special occasions, while usually there will be comparatively few persons with ordinary illumination, a modification of this vertical-tube system will give good results when the external temperature is not too low. These air ducts may be made of zinc or galvanized iron, and be brought up in the jambs of the fireplace. If there be a high mantel, the openings of the tube may be on a level with the mantel and covered with a wire grating, which may be double to permit of the insertion of cheese cloth or a thin layer of cotton batting to serve as a filter. If the mantel be a low one, the tubes may be carried up to a height of from 6 to 8 feet above the floor, and open through a bracket or pedestal. These tubes may be about 4″x6″, opening to the external air through perforated terra-cotta panels, or by openings covered with wire netting painted the same color as the surrounding wall, and should have dampers or butterfly valves, which can be worked from within the room. The external opening may be at any convenient height to suit the exterior appearance, but the vertical portion of the tube should not be less than 3 feet in length.

Such tubes are commonly known as Tobin's tubes. They are liable to become receptacles for dust, dead insects, etc., and to become obstructed by cobwebs, so that they require attention as to internal as well as external cleanliness. Mr. Tobin supposed that if these tubes were used there would be no need for special outlets, but this is an error —they work well only where there is an outlet flue properly arranged.

In some cases the air may be brought in and distributed by perforated cornices, with good effect. In all cases in which the air is introduced through many small openings, it is well to have these openings trumpet-shaped, flaring inward to facilitate the rapid diffusion of the current, and the ordinary cast-iron wall registers could easily be

much improved in this way by making the bars triangular with the apex towards the room.

There are many forms of window inlets, the simplest, next to opening the window itself, being formed by raising the lower sash about 6 inches, and placing a piece of board so as to fill the space thus left between the bottom of the sash and the sill. There is thus formed an opening between the lower and upper sashes through which the incoming air streams upward. This may be supplemented by having the board perforated with one or more 4-inch tubes bent upward on the inside, and having within them a damper, or butterfly valve to control the current.

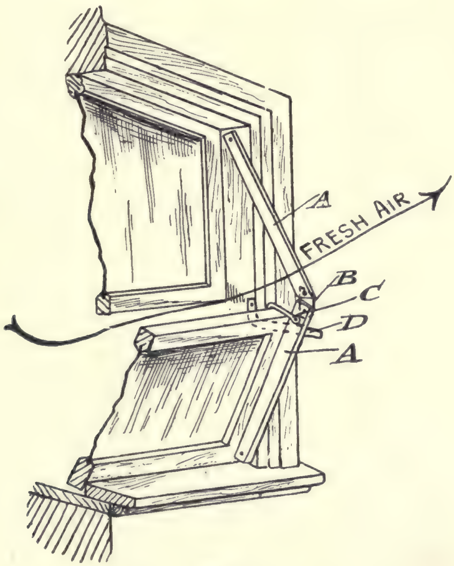


FIG. 35.

Another form of window ventilator, suggested by Dr. Rosebrugh,* consists of a short supplemental sash placed outside of the window at the top, close against the top part of the upper sash. When the top sash is lowered, this extra sash prevents a direct draught from the top of the window while the air enters in the space between the upper and lower sash.

Still another simple form of window ventilator which is said to work very satisfactorily, is shown in Figs. 35 and 36, taken from *The*

* Canadian Practitioner, XVII., 1892, p. 103.

Engineering Record for June 13, 1891. The side strips securing the lower sash are omitted on one side, and on the other they are made in two pieces *A A*, pivoted top and bottom and united in the middle by a slotted hinge *B*, thus permitting the lower sash to tip inwards and leave an open space at its top, while the bottom remains close against the window seat.

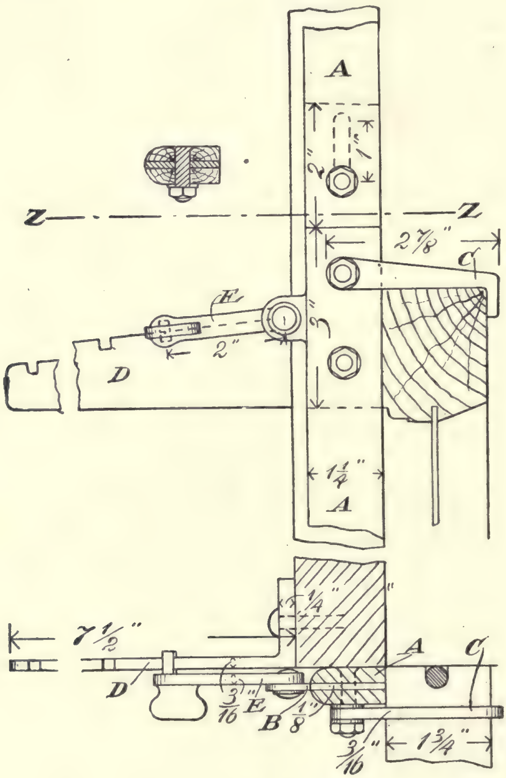


FIG. 36.

The upper part of Fig. 36 is an elevation when the sash is closed, the lower part is a section at *Z Z*. *C* is a hook securing the sashes in a closed position. *D* is a graduated bar to regulate the amount of opening, and *E* is the latch.

In connection with systems of air-heating by indirect radiation, it is very desirable to provide means by which it shall be possible to

quickly control and vary within certain limits the temperature in a given room without interfering with the fresh-air supply.

In the majority of cases this can be best effected by providing switch valves in connection with the fresh-air ducts and radiators, so arranged that by turning or pulling a handle placed in the room to be warmed, an inmate of that room can compel the fresh incoming air to either pass wholly through the box or case containing the radiators, or wholly outside of it, or partly through and partly around it, so as to produce by mixture any temperature desired.

Many different ways of arranging such a switch valve can readily be devised. The following are illustrations of various forms, which

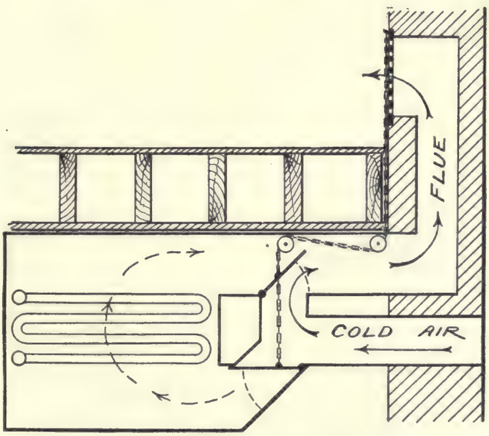


FIG. 37.

will be found suggestive and which are for the most part self explanatory:

Figure 37 shows a simple and cheap form of such a valve, proposed by Messrs. Gillis & Geoghegan, of New York City.

Figure 38 is a form used by Baker, Smith & Co.

Figure 39 shows a more satisfactory, but more expensive pattern, proposed by Mr. C. W. Newton.

Figure 40 shows the switch-valve arrangement employed in the Johns Hopkins Hospital, in Baltimore, in connection with the hot-water coils placed beneath the wards.

Figure 41 is the section of a form of radiator and switch valve recommended for hospital use by Dr. Norton Folsom, of Boston.

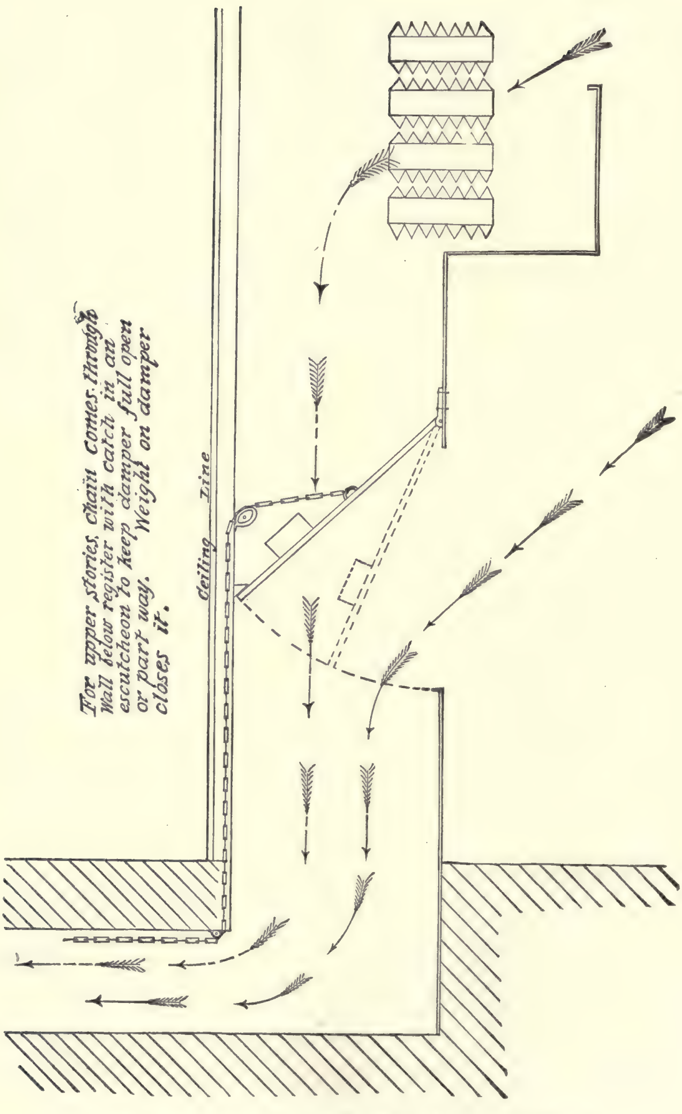


FIG. 38.—SWITCH VALVE FOR HEATING COILS.

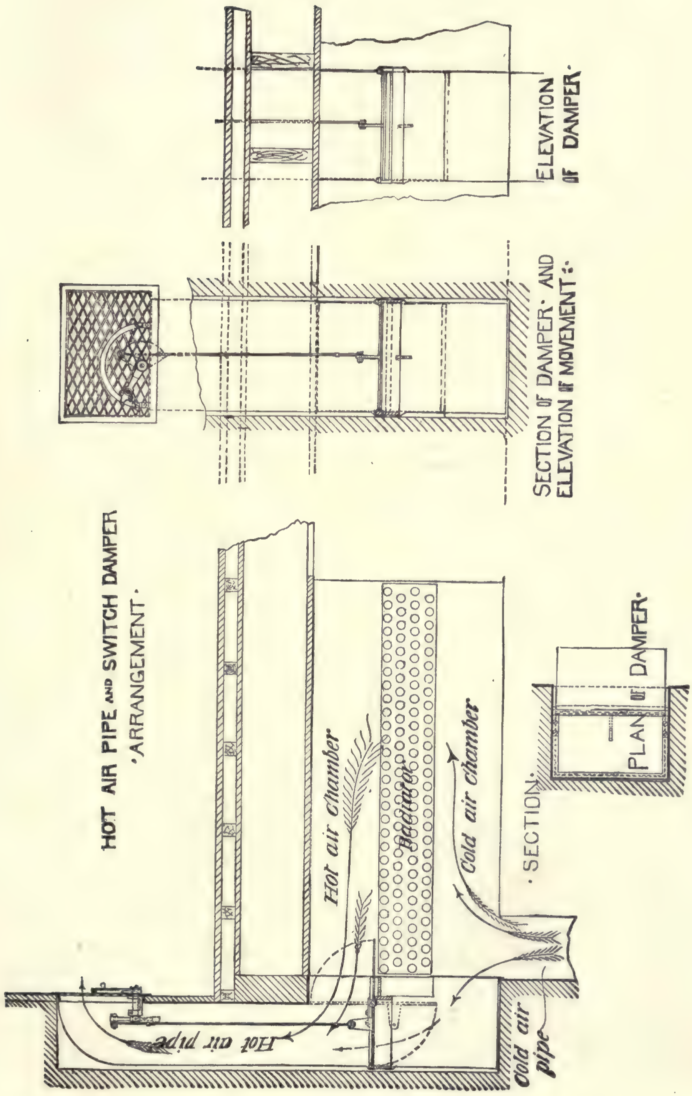


FIG. 39.—NEWTON'S SWITCH VALVE FOR STEAM-HEATING COILS.

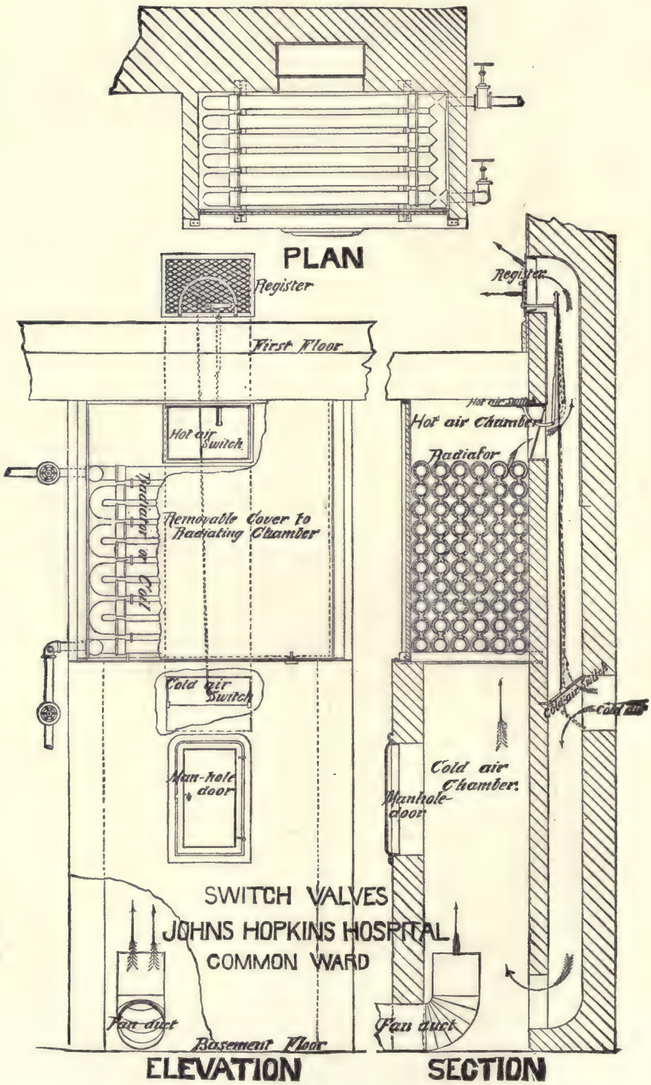


FIG. 40.—HEATING COILS AND SWITCH VALVES.—JOHNS HOPKINS HOSPITAL.

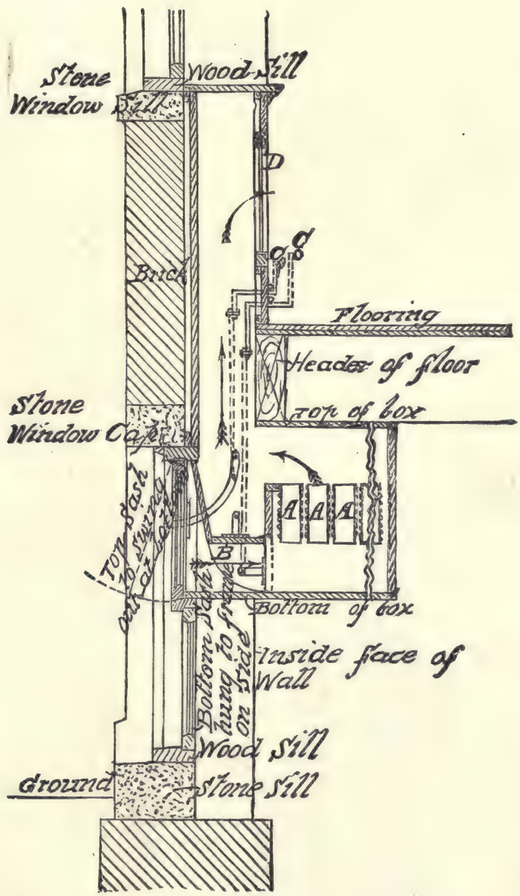


FIG. 41.—SWITCH VALVE RECOMMENDED BY DR. N. FOLSOM.

The "switch" or "mixing valve" shown in Fig. 42 was designed by Mr. A. Mercer, of New York, for the Bridgeport Hospital.

The casings of the radiators are metal, with a by-pass at *a*. The valve consists essentially of the damper *a*, rod and crank *b*, lever *c*, and pull *d*, with the set or thumb screw *e*. The rod at *d'* may be marked

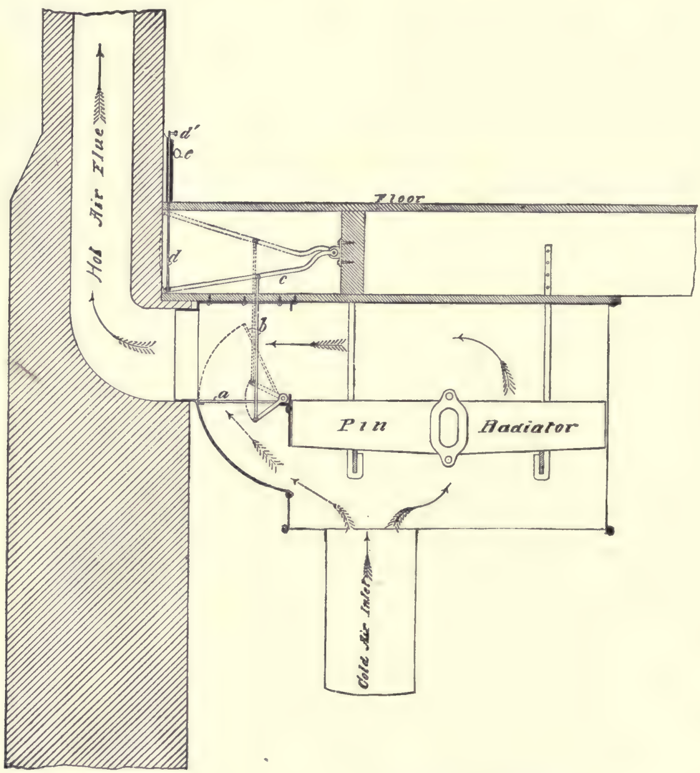


FIG. 42.—DETAIL OF MIXING VALVE.

to degrees or fractional parts of the opening, and in other respects the sketch shows for itself.

Figure 43 illustrates another form of "switch valve," in which all the movable parts are in the register. It was designed by Mr. William J. Baldwin, of New York, for the Moses Taylor Hospital, at Scranton, Pa.

The hospital is on the pavilion plan, the wards being a single story. The air from a blowing fan enters the basements under the wards, where it is to be warmed to about 60 degrees, by being passed through a large coil, which utilizes the exhaust steam from the engine which drives the fan. This converts the basements into a plenum, from which the air can be passed to supplementary steam coils on its way to

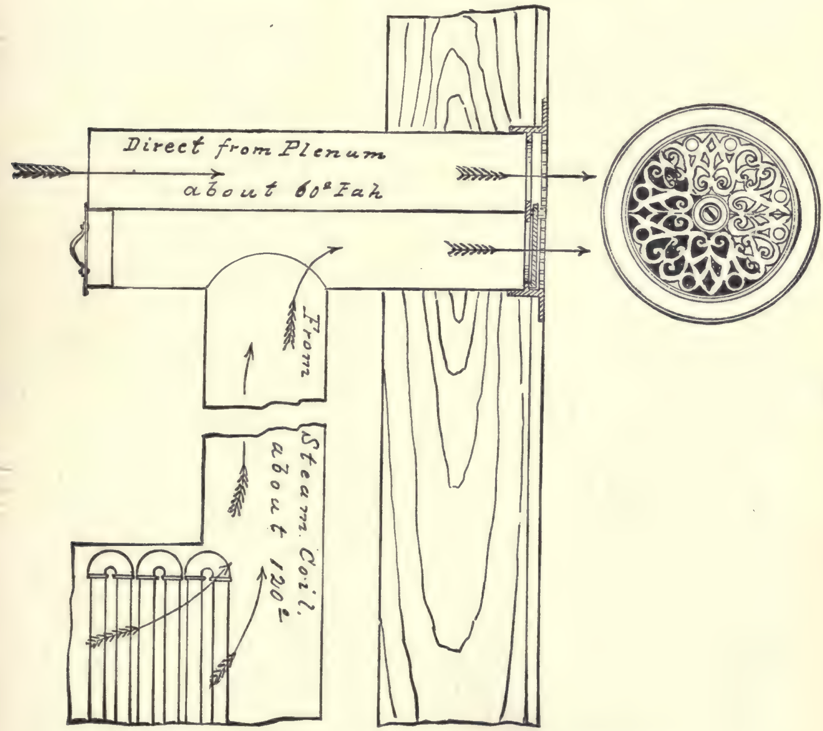


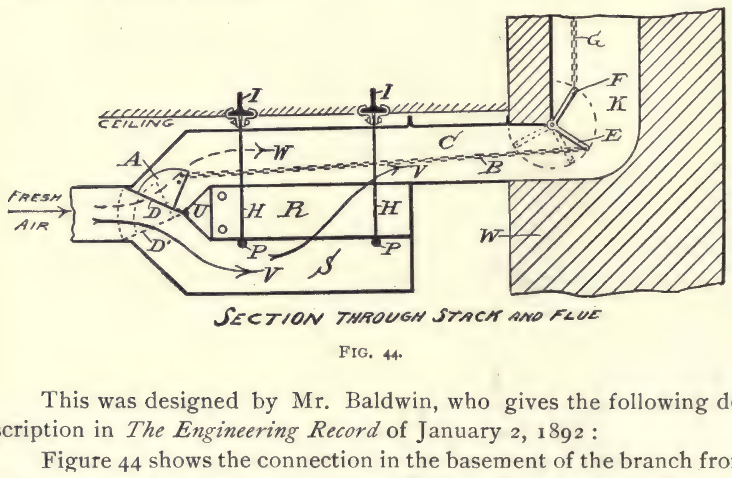
FIG. 43.—PLAN AND SECTION OF MIXING REGISTER.

the wards, and be made warmer, or it may be passed direct into the wards, or any mixture of the air at the two temperatures may be passed in, but by no means can the air supply be reduced. It is a circular register to all outward appearance, and is connected with a sheet-iron tube, which goes through the floor. This tube is divided its whole length by a septum, so as to form two semi-circular tubes. One of

these halves is connected to the supplementary-coil chamber, and has a stopper at the bottom, while the other half is open. The register, instead of having valves in the ordinary way, has a solid semi-circular disk, which can be revolved under the fretwork by a key introduced into the slot in the middle, as shown. This semi-circular disk may be turned so as to close one or other of the semi-circular pipes, or it may be made to cover one-half of each, so that one-quarter of the fretwork is delivering air at 60 degrees, while another quarter is delivering air at 120 degrees, or any other proportions of the two currents may be obtained by shifting the position of the semi-circular disk without reducing the volume.

A modification of this register for side-wall flues has also been designed by the same person.

The method used in the Orthopædic Hospital, in New York, is shown in Figs. 44 and 45.



SECTION THROUGH STACK AND FLUE

FIG. 44.

This was designed by Mr. Baldwin, who gives the following description in *The Engineering Record* of January 2, 1892:

Figure 44 shows the connection in the basement of the branch from the blast main, with a vertical flue *K* (8″x15″ or 20 inches), in the 20-inch brick main wall *W*. *S* is a galvanized-iron stack, with conduit *C*, and contains an indirect steam radiator *R*, which rests on heavy iron-pipe bearers *P P*, which are supported by hangers *H H*, and clamps to the iron floor beams *I I*. The damper *D* is hinged to a solid frame *U*, so that the outer end is always inside the blast pipe. *A* is a lever arm for operating *D*, and is made so heavy as to weight it and carry it down positively when released. *B* is a safety chain connecting *A* with the lower arm *E* of bent lever *F* at the foot of the wall flue. *F* is connected by chain *G* with lever *L* (Fig. 45), which is fixed

on the ⅝-inch square shaft *M*, that works in a hole drilled in the wall just above the register. One end of *M* works in a gas-pipe thimble bearing *N*, and the other is turned to fit a hole drilled at *T*, in the center of a brass sector *R*, to which it is secured by a nut *S*. The

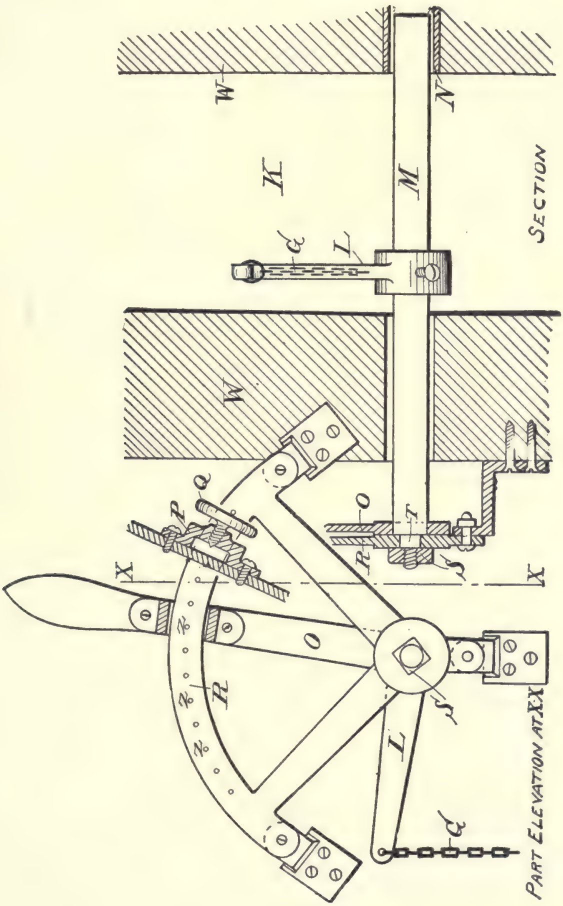


FIG. 45.

sector *R* is screwed on to the finished interior face of the wall, and on it works the hand lever *O*, which is fixed on shaft *M*, and can be set at any part of the arc by the set screw *Q* in guide bar *P*. The operation

of levers and dampers is evident. The air may be mixed to the desired proportion of hot and cold by setting lever *O* at any of the intermediate positions *Z Z*, etc., so as to let damper *D* occupy a corresponding intermediate position and allow part of the air to enter above and part below the radiator, but in whatever position it is the inlet is never closed but must always admit a full quantity of air.

The levers are made of brass, and nickel-plated where exposed to view. Just below sector *S* is hung a thermometer on the face of the register, and it is found possible to regulate the temperature within 3 degrees of any required point.

Still another device of Mr. Baldwin for the same purpose is shown in Fig. 46. This is used in the building of the College of Physicians and Surgeons in which both heated and cool air are brought in ducts, under pressure to the several rooms.

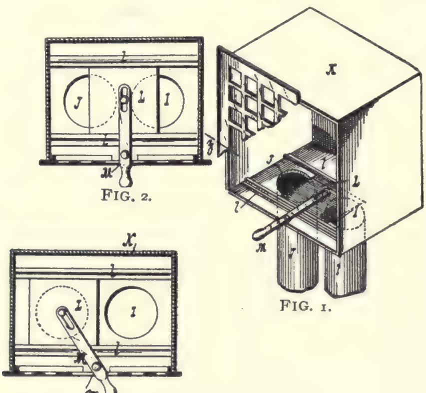


FIG. 2.

FIG. 1.

FIG. 3.

FIG. 46.

The twin ducts, supplying warm and comparatively cold air, are fitted with heads *K*, Fig. 1, placed in the various rooms of the building and set into the walls. The warm and cold-air pipes *I* and *J* open into the bottoms of these heads and are controlled by the valve *L*, shown also in Figs. 2 and 3. The warm and cold air, discharging from the ducts *I* and *J*, mixes in the head *K*, and enters the room through the side opening. The valve *L* consists of a slide, guided across the duct openings by the guides *l l*, and operated by a lever *M*, which is pivoted to the head *K*. The slide is of such a length that when in a

position central between the duct openings it closes one-half of each of these. Consequently when the slide is moved in a direction to close one of the openings, the other is proportionately opened (Fig. 2). A full supply of fresh air is thus always obtained.

Figure 47 is a cross-section of a form of by-pass radiators devised by Dr. A. C. Abbott for the dog hospital of the department of Veterinary Medicine of the University of Pennsylvania, being a modification of that used in the Laboratory of Hygiene previously shown in Fig. 32.

A wooden box lined with tin, located beneath the window sill *S*. The box is divided longitudinally by the partition, which does not

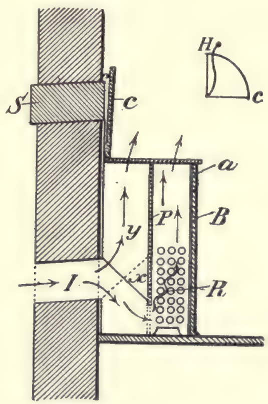


FIG. 47.

reach to the floor, but allows sufficient space for passage of air from the air inlet *I*, to the radiator *R*. The box can be closed and air supply cut off by the swinging cover *C* in the cut hooked back against the sill of the window. The front of the box *B* also swings out on a hinge, thus permitting access to radiator.

The top of the box through which the air enters the room is covered by cheese cloth dust filters which rest between two layers of wire netting. *x* represents a damper fan directing the air entering the room either through the section *y* of the radiator, in which case the air is not warmed, or by reversing its position the air is directed over the radiator *R* and enters the room as warm air. The two extreme positions of the damper *x* are represented by the intersecting dotted and con-

tinuous lines. By placing it intermediate between these extremes part of the air enters the room without passing over the radiator while the remainder is warmed by passing over the radiator.

The quadrant to the right of the cut indicates the lever to be placed on the outside end of the box; when the lever is opposite *H* only hot air enters, when opposite *c* only cold air, when intermediate between the two, air of medium temperature comes in.

It is very desirable that some form of valve calculated to effect the purpose for which the above are suggested should be used much more extensively than is at present the case, and it is in this direction that the most immediate and important improvement of ventilation of dwelling houses in this climate can be effected.

Nor should the application of this method be confined to steam and hot-water heating, seeing that it is quite as important, to say the least, in furnace-heated houses. At present, in the most costly dwellings heated by indirect radiation, the only way to promptly diminish the heat when it becomes oppressive is to close the register, and shut out the fresh air as well. It may be well, however, to warn the architect or heating engineer that to obtain good results from this device it is necessary that the occupants of the room should know how to use it, and should be willing to do so, and that to secure this willingness, it is desirable to obtain their co-operation. Such valves were provided for the radiators supplying the private parlors in a large club house in New York, and the louvers or dampers were removed from the registers to prevent persons who did not understand the apparatus from shutting off the air. The result was that some of the members insisted on having the louvers replaced in order that they might be able to turn them as they had been accustomed to do. A little educational work would not have been wasted in this instance.

CHAPTER XII.

FOUL-AIR OR UPCAST SHAFTS—COWLS, SYPHONS.

IN the preceding chapter some remarks have been made with regard to the proper position for foul-air registers, the general rule being that in cold weather, in all rooms except legislative halls and theaters, such openings should be near the level of the floor, to draw off the air which has been cooled by windows and walls, and to prevent undue loss of heat. This forms what is called "downward ventilation." In moderate weather when the air is not artificially warmed, it is preferable that the foul-air registers should be in the upper part of the room, and they may open into the flues with which the lower openings, for use in cold weather, are connected. So far as the production of draughts is concerned, there is no objection to a velocity of current of 6 or 8 feet per second through the foul-air outlets, but it will not do to assume that the current will have that velocity and adjust the size accordingly. If what is called natural ventilation is to be relied on, a velocity of 5 feet per second in lower rooms, and of 4 feet per second in upper rooms forms the safest basis for calculation. If aspiration by a fan or heated flue is employed the velocity may be assumed to be 6 feet per second.

As a rule, wall registers opening into foul-air flues are unnecessarily and improperly constructed with an excess of ornamental ironwork, louvers, etc., which greatly obstruct the passage of the air. In large rooms, barracks, school rooms, etc., it is better to omit the register and put in its place a solid shutter which may be made to either slide or swing, and which can be adjusted so as to leave the outlet entirely open or entirely closed.

The remarks in the preceding chapter with regard to calculating sizes of fresh-air flues, apply also to foul-air flues. In all large flues of this kind the average velocity may be assumed to be 6 feet per second. If, for example, in a small hospital ward the amount of air to be supplied and removed is fixed at 72,000 cubic feet per hour, or 20 cubic feet per second, then a single foul-air shaft for such a ward should have an area of about 3.⅓ square feet.

In arranging the ventilation for a large building of several stories, the architect may choose between several different systems in planning

his foul-air or upcast shafts. Suppose, for example, that the building in question is a large school house or a hotel, or a building containing a large number of offices.

In the first place, he may give a separate foul-air shaft to every room, which shaft shall pass directly upward to the outer air above the roof. The simplest way to do this is to give a fireplace and separate chimney flue to each room. The objections to this are the increased cost, the difficulty of arranging so many flues and chimneys in the walls and on the roof—increased danger from fire, and the risk that one flue will pull against another.

In buildings of such size and importance that it is worth while to provide some form of centralized heating for them by means of steam or hot water, the architect will usually prefer to gather the majority of the foul-air flues into a few, and, if possible, one large upcast shaft, in connection with which he can provide means to secure a constant current, and to regulate its velocity to suit the varying requirements of the season or of the inmates of the building. This collection of the flues into a central shaft may be effected in four different ways, which are well discussed and illustrated by Planat.*

The first of these is what Planat calls aspiration from above, by which he does not mean aspiration from the upper part of each room, but from a point above all the rooms—usually in the attic—to which point all the foul-air flues are made to converge and enter a single shaft, in connection with which is a furnace or coil of steam pipe to give additional heat and ascensional force to the air.

The second method is to carry the foul-air flues of each story horizontally to the central shaft which they enter at the level of the ceiling, which may be termed aspiration on a level or horizontally. The third method is to carry all the foul-air flues downward to the cellar, where they are collected into a duct, or ducts, leading to the central upcast shaft. This is the aspiration from below of Planat. The fourth system is a combination of the first and third, the rooms in the upper story having their flues passing upward, while the remaining floors are ventilated by flues passing downward.

In selecting from the various methods the one to be used in a particular building, the architect should be governed by the following considerations:

First.—It is desirable to reduce the number of main foul-air shafts or ventilating stacks as much as possible. One is better than

*P. Planat, Cours de Construction Civile, Première partie. Chauffage et Ventilation des lieux habités. Paris, 1880.

two, and there are very few buildings in which more than two such shafts should be used. With one large chimney the friction is reduced to a minimum, the arrangements for control of the velocity can be simplified, and all risk of one aspirating shaft pulling against another is avoided. The question as to the employment of one or two shafts must be determined by the plan of the building and the possibility of placing the shaft in a nearly central position.

Second.—In the second, third and fourth systems above referred to, the shaft will usually be built of brick, and be of nearly uniform diameter from the bottom up. It will also in most cases be convenient to carry the smoke pipe from the heating apparatus upward within this shaft. Such a shaft as this occupies more space than might at first be supposed. It will be remembered that the velocity of the air in it should not exceed 6 feet per second. If, then, it is to give passage to 216 cubic feet per second—which implies a building of a size to accommodate between two and three hundred persons—the chimney must have 36 square feet of clear inside area. Such a shaft will probably reach 100 feet in height, requiring thick walls at the bottom, and it will be found necessary to provide nearly 100 square feet of area for it.

In the first system above referred to, it is not necessary to carry the large central shaft up through every floor. The shaft begins in the attic, and may be made of wood, if properly lined, or of galvanized or boiler iron, according to its size.

Third.—In the first system the number of flues in the walls increases with the height; in the third system the reverse occurs. In other words, in the third system the walls are weakest below, just where they have the most weight to carry, and therefore should be thicker than when the first system is used.

Fourth.—The application of heat to the central shafts can be arranged more easily and to much better advantage in the third system than in either of the others. During the winter the heat needed for this purpose can be obtained in most cases from the smoke flue from the heating apparatus, while in summer a small furnace can easily be connected with the side of the base of the shaft. As the aspirating power of the shaft depends on the height of the heated column of air as well as on the difference between the temperature in the shaft and that of the external air, it is evident that the nearer the bottom of the shaft the extra heat is applied, the greater will be its efficacy, bearing in mind that it must be applied at a point above the entrance of all foul-air flues. In the first plan it will usually be found most conven-

ient to apply the accelerating heat by means of a coil of pipe lining the shaft and heated by steam.

The difference in the cost of maintenance for systems one, two and three, has been computed by Planat for a building four stories high, having a ventilation of 39 cubic feet per second.

He finds that with system one, it would be necessary to burn seven pounds of coal per hour to heat the shaft; with system two, 5½ pounds, and with system three, 4.1 pounds. The third system is therefore much the least costly of the three as regards maintenance, and it also secures greater uniformity of action and is more convenient to manage, for which reasons it should in most cases be preferred. In an old building, however, it is often much easier to apply the first system, and in some it is the only one which can be used.

When system one is employed, all foul-air flues should run in or against inside walls in order that they may lose as little heat as possible. In system three this is a matter of less importance, although in this also it is desirable to keep the foul-air flues warm, but in this system it is necessary that the central shaft shall be kept constantly heated, summer and winter. If it be allowed to cool off in summer, there will probably be a backward draught through the foul-air flues at certain times during the day when it is cooler in the building than it is out of doors, and it will then be found very difficult to start a fire to warm the shaft. If the building is a high one and has a central hall reaching to the roof, it is necessary to take special care to make the upper part of this hall as air-tight as possible, for otherwise it may easily become a powerful ventilating shaft and antagonize the apparatus designed for ventilating purposes, besides wasting a great deal of heat.

If the upcast aspirating shaft or chimney is to be so arranged as to regulate the velocity of the current in it, this should not be done by valves or dampers at or near the base, because if the velocity at the top is too small, the draught may be interfered with by winds. The best arrangement seems to be to put double valves at the top so that the outlet opening can be closed more or less at pleasure. Fig. 48 shows the plan, and Figs. 49, 50, sections of the tops of ward aspirating chimneys in the Johns Hopkins Hospital in which this mode of arranging the valves has been adopted.

Within the last 50 years a vast amount of ingenuity has been expended upon devices to be placed at the mouths of tubes, flues, or shafts, for the purpose of giving direction to air currents passing through them, or of enabling the wind to produce, accelerate, or pre-

vent such currents. These devices, commonly known as ventilators, have of late been patented in endless variety, and about a dozen new ones are added to the list every year.

The outlet ventilators, which properly include all forms of chimney caps or terminals for smoke, as well as foul-air flues, were probably first planned to prevent the entrance of rain or snow into the flues, and this is still one of their most important uses. Their action depends upon two facts connected with the movement of fluids.

The first of these is what is sometimes called the law of the lateral communication of motion in fluids—the fact that a fluid in motion tends to communicate motion, in the same direction, to other portions of fluid immediately connected with it.

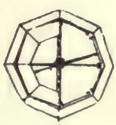


FIG. 48.

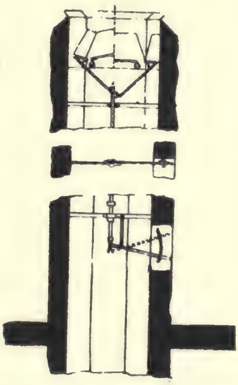


FIG. 49.

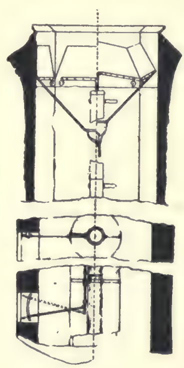


FIG. 50.

The second fact is the tendency of air to adhere to surfaces. When a current of air strikes a surface it is not reflected at an angle equal to the angle of incidence, as a ray of light or a billiard ball would be, but it is spread out in a thin layer upon the surface. In a valuable series of papers by F. Savart, published in the *Annales de Chimie et de Physique* for 1833, it is shown that "When a jet of water strikes a truncated cone perpendicularly to its axis, and just above its lower base, it spreads out, covering more than half its surface, and, rising upward, leaves its upper base in a continuous sheet, vertically, in a plane nearly coinciding in direction with that of the sides of the cone, and horizontally, nearly in the direction of tangents to the surface of the cone, while a small portion only of the fluid forms two

small streams, which drop down from those two points of the lower base of the cone which are at right angles with the original direction of the jet.

"When a jet meets a plane at its center and perpendicularly, it forms a continuous sheet over the whole surface, thin in the center and thicker towards the circumference.

"Both the direction and continuity of this sheet are preserved far beyond the borders of the circular plane, where its edge is thin, but it follows more or less the direction of the curve of the edge, if it is thick and rounded.

"When a jet of air infringes upon a surface of limited extent, the atmospheric pressure upon the opposite side of the surface, in consequence of the lateral communication of motion, is diminished, and a current will be established through a tube, one of the extremities of which is placed in the point of diminished pressure, and the other beyond the borders of the surface. This is the important principle upon which the efficiency of ventilators and chimney tops depends; it is also important in its bearing on the position of the mouths of air-trunks for hot-air furnaces; if the mouth be placed in a point of diminished pressure, on the leeward side of a building, air may pass outward, especially from apartments on the windward side of the house."

As Dr. Wyman points out, "A simple demonstration of these propositions may be obtained by means of a card and candle. If a blast from the mouth be directed obliquely against a card, the flame of a lighted candle will be drawn towards the card, on whatever side of it the candle is held. Increasing or diminishing the velocity of the blast does not change the direction assumed by the flame, but only the velocity with which it is drawn toward the card.

"If the blast be directed perpendicularly upon the center of the card, the flame when passed around the edge of the card will be driven outward at all points; and if the candle be held near the blast and at a little distance from the plane surface, the flame will, in virtue of the lateral communication of motion, be drawn toward the surface, and yet, by the current air close to and parallel with the card, it will be prevented from reaching it. A strong flame may thus be made to play apparently with great force upon the hand, and yet not burn it. An illustration of this principle may often be observed in the narrow pathway, so convenient for foot passengers, found after a snow storm on the windward side of a high and close fence."

In accordance with these principles, it is easy to see that when a current of air flows across the open mouth of a simple cylindrical tube

it must exert a certain aspirating power upon the tube, or that a small stream of air directed through a large tube tends to set in motion the entire contents of the tube, upon the principle of the well-known Giffard's injector.

The object of all cowls is to present such a surface to the wind that the sheet of moving air produced shall, on leaving the surface, be moving at such an angle to the column of air contained in the flue as to exert the strongest aspirating effect upon it. The strength of this aspirating effort varies, within certain limits, with the velocity of the currents, and also with the angle which is made by the current with the axis of the flue.

Some of these cowls are made to revolve with the wind; others are fixed, and present in every direction the same form of surface and opening. As Dr. Wyman remarks, there are few objects upon which so much time has been spent and misspent; and their great variety and the constant changes in their arrangement are proofs that more is expected of them than they accomplish, and that the principles on which they act are not well understood.

The effect of outlet cowls, when placed at the top of vertical shafts or flues, has been the subject of several sets of experiments.

The first of these to which I shall refer were made in 1842 by Messrs. Ewbank and Mott, and the results were reported by them in the *Journal of the Franklin Institute*, 3d series, Vol. IV., 1842, p. 104.

They directed a strong current or blast of air from bellows across the top of a glass tube, an inch and a quarter in diameter and 28 inches long. The lower end of this tube was dipped into a vessel of water, and on the upper end were successively placed tin models of the various forms of cowls experimented on.

The greatest rise of the water column, showing the strongest aspiration, was obtained by the use of a short conical tube, placed at right angles to the glass tube, and having the blast directed through it from the small toward the large end.

These experiments, however, cannot be considered to be of much value, for the cross current used was stronger than a violent hurricane, and it is not safe to rely upon obtaining with full-sized flues the same results as are shown by glass-tube models in the movements of air currents.

A much more extended and valuable series of experiments upon the effect of various forms of outlet cowls was made by a committee appointed for this purpose by the American Academy of Arts and Sciences. The report of this committee, to which I have already re-

ferred, was prepared by Dr. Morrill Wyman, and will be found in Vol. I., of the *Proceedings of the Academy*, Boston, 1848, p. 307.

In these experiments a constant current of air, produced by means of a revolving fan, was used to produce an induced current in a tube, having its long axis at right angles to that of the blast; the velocity of the current thus produced being measured directly, and not by its power of sustaining a weight, or head of water, or other statical effect, which method the committee remarks is decidedly objectionable. "Such a measure gives the correct value of the initial force or tendency to establish a current in a chimney in which there is no actual movement; but it does not indicate the velocity of the current which will be the final result of the action of the ventilator, nor is it any measure of this final velocity when ventilators of different construction are compared together. Mechanics and engineers are familiar with the differences between statical and dynamical effects of a force. In the air pump the dynamical value of any amount of exhaustion is equal to the power required to produce it, and is, therefore, proportioned to the magnitude of the receiver when other circumstances are the same; whereas, its statical power, or its power to sustain a head of water, is wholly independent of the magnitude of the receiver, and proportioned solely to the tension of the air within it."

To measure the current, a leaden pipe 1.25 inches in diameter and 53 feet in length was placed near and a few inches below the mouth of the blowing machine. In the mouth of the trunk, attached to the blowing machine, was a tube of tinned iron of the same diameter as the pipe, and bent at a right angle; the upright branch, about 6 inches long, reaching to the middle of the mouth, while the horizontal portion, about 5 inches in length, reached to within 2.5 inches of the end of the leaden pipe. Each ventilator, when examined and tested, was placed upon the upright portion of this tube. For this purpose the ventilator had through it, or attached to its side, a corresponding tube of the same diameter. The velocity of the blast was 10.36 feet per second, or 7.06 miles per hour. With the blast passing across the top of a perpendicular fixed tube cut at right angles, the velocity of the induced current was 0.728 feet per second; with a straight tube, cut off obliquely at an angle of 45 degrees, opening turned from the blast, the velocity was 1.325; with a truncated cone, the velocity was 1.71 feet per second; with a cone with cap, as laid down by De Lyle St. Martin, lieutenant in the French Navy in 1788 (see Fig. 51), the velocity was 1.56. St. Martin's cone without the cap gave a velocity of 2.21.

The cone was proposed as the proper form for the chimney top, and an account of its application was published by Count Cisalpin about 100 years ago. The adjoining figure (52), is an elevation from the perspective view given in the memoir. This, slightly modified (Fig. 53), is what is generally known as the Emerson ventilator, and is one of the best of all the various forms of cowls. The best form of cowl, as shown by the report of the committee just referred to, and the one which I prefer for all upcast shafts, is shown in Fig. 54. There are now no patents upon any of the cowls just described.

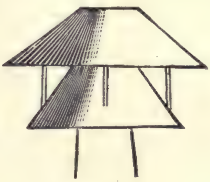


FIG. 51.

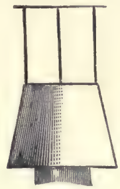


FIG. 52.

This matter of terminals of foul air and smoke flues occupies such a prominent, although for the most part wholly unmerited, place in the literature of ventilation, and so much stress is laid upon the merits of this or that particular form of cap or cowl, not only by patentees, but by some architects, that a few more words on the subject seem necessary.

Dr. Wyman remarks that in a strong wind any cap will be effectual which prevents the wind from beating down the chimney. "In a

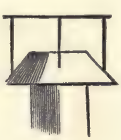


FIG. 53.

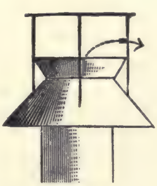


FIG. 54.

light, unsteady wind, the time when the cap is most needed, it is subject to a disadvantage which it is difficult to obviate. The friction is always considerable, and, under the circumstances just mentioned, the opening of the cowl will often be directed toward the wind; in this position the wind will have but little influence upon the vane, and the smoke, if the draught is feeble, will be driven into the apartment.

"The steadiness of the cowl may be increased by making the vane double, the two sides forming an angle of 10 or 15 degrees (<). The single vane in common use, receiving no pressure from the wind when in its direction, has the same tendency to flap as a loosened sail. The friction may be diminished by nicer workmanship, and the noise lessened by allowing the cowl to run in leather collars; but the objection we have alluded to will only be diminished, not removed."

Dr. Wyman speaks favorably of a form of cowl which consists of a conical cap balanced on a point so that it can be tilted in any direction. The wind blowing upon it depresses the side upon which it strikes, and at the same time elevates the opposite side.

In 1878 a series of experiments were made at the Royal Observatory, Kew, England, upon ventilating exhaust cowls, by a committee composed of W. Eassie, Rogers Field, and Douglas Galton, whose names are a sufficient warrant for the care with which the tests were made. The cowls thus tested were the air-pump ventilator of Boyle and the injector cowl of Mr. Lloyd, which is a fixed cowl like that used by Captain Liernur, of Amsterdam. Four upright iron tubes, each 6 inches in diameter and 12 feet long, were so arranged as to receive equal air supply below, and the same exposure to wind above the roof of the building in which they were placed, and above which they projected about 2 feet. On three of these tubes the cowls above mentioned were fixed, while the fourth was left as a plain open tube, to serve as a standard of comparison. The results are given in the following report, which is a model of brevity and clearness:

"The sub-committee appointed at Leamington to test the ventilating exhaust cowls beg to report that they have given the matter their most careful attention, and carried out at the Royal Observatory, Kew, an elaborate series of about 100 experiments, on seven different days, at different times of the day, and under different conditions of wind and temperature. After comparing the cowls very carefully with each other, and all of them with a plain open pipe as the simplest, and, in fact, only available standard, the sub-committee find that none of the exhaust cowls cause a more rapid current of air than prevails in an open pipe under similar conditions, but without any cowl fitted on it. The only use of the cowls, therefore, appears to be to exclude rain from the ventilating pipes; and as this can be done equally, if not more efficiently, in other and similar ways without diminishing the rapidity of the current in the open pipe, the sub-committee are unable to recommend the grant of the medal of the Sanitary

Institute of Great Britain to any of the exhaust cowls submitted to them for trial."

Of course, this report was by no means satisfactory to the inventors and proprietors of patent cowls, and in this respect it corresponds with the previous reports to which I have referred before. Each inventor obtains very different results from his own experiments, and there seems to be no immediate prospect of reconciling the discrepancies.

Mr. Hellyer, in the second edition of his work on "Plumbing and Sanitary Houses," has an interesting chapter headed "Ventilation, or Cowl Testing, but not at Kew," in which he gives the results of a number of experiments made with cowls of different kinds. He concludes that, while the power of a cowl to cause an upcast of air through the pipe is not so great as some suppose, it certainly is greater than the report of the Kew Committee would lead us to believe.

He "considers that cowls should be fixed on *all* ventilating pipes for *foul air*, not so much for assisting the *up draught* as for *preventing* a *down draught*, especially where the air *blown down* through such ventilating pipes would come out near a window or door, where it should be *sucked* into the house." (The italics are in the original.)

His experiments were made with two 4-inch lead pipes, each about 32 feet long, the tops being about 6 feet above the roof and 4 feet apart. In one of the chief systems of testing, the bottoms of these pipes were connected by a pipe in the form of the letter U, so arranged that an anemometer could be inserted and observed through a glass door. By this apparatus a cowl can be tested against another cowl or against an open pipe on what the author calls the "Pull, devil, pull, beggar principle."

Mr. Hellyer concludes that the best cowls are better than open pipes; that the relative value of various cowls varies according to the different states of the atmosphere; that, on the whole, the best cowl is one of Mr. Buchan's, and that of Mr. Hellyer's comes second.

Many attempts have been made to combine the inlet and outlet in the same ventilator, and this either with or without connecting them with the heating apparatus. Of those combining the inlet and outlet in a single tube or shaft, which is intended or supposed to be entirely independent of the heating, the principal forms are the ventilators of Watson, Muir, M'Kinnell, and Macdondald; the first three of which are described and figured in most English works on hygiene or on ventilation. All of these are intended to be inserted in the center of

the ceiling of the room or space to be ventilated, and the best of them is probably the double tube of M'Kinnell (Fig. 55). "It consists of two cylinders, one encircling the other, the area of the inner tube and encircling ring being equal. The inner one is the outlet tube; it is so because the casing of the other tube maintains the temperature of the air in it; and it is also always made rather higher than the other. The outer cylinder or ring is the inlet tube; the air is taken at a lower level than the top of the outlet tube, and when it enters the room it is deflected toward and spread over the ceiling by a flange placed on the bottom of the inner tube. Both tubes can be closed by valves."

The Macdonald ventilator is recommended in the last edition of Parkes' "Hygiene," where it is figured and described. It is similar to the M'Kinnell tubes, but has a fan within the tube which is driven by

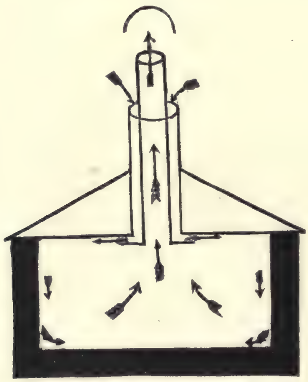


FIG. 55.

another fan placed on the top of the tube, the result being that no reversal of the current is possible so long as there is wind enough to give motion to the fan. It seems, however, rather complicated and costly. By making the motile fan much larger, and self-regulating to secure a constant velocity, as is done in many of the modern American windmills, this principle might be made useful in some cases.

These double-tube ventilators are especially applicable to buildings containing but one room, and where doors and windows are very rarely opened, but they are useless in dwelling houses. When a door or window is opened in the room in which they are placed, their action either ceases altogether or they become upcast shafts—while, if there is an open fireplace in the room, they become inlets.

To illustrate the use which may be made of these tube ventilators, under exceptional circumstances, the reader may consult a paper by Dr. J. N. Radcliffe, which will be found in full in the *Sanitary Review*, for 1858, vol. 4, p. 343. During the Crimean War, Dr. Radcliffe had occasion to take charge of a number of sick, placed in a small shed, lit by two small windows, the sashes of which were fixed, the only opening for either ingress or egress of air being the door. This shed contained 13 patients. It had a tiled and sloping roof, and a ceiling at a height of about 10 feet. The days and nights were somewhat chilly, and any

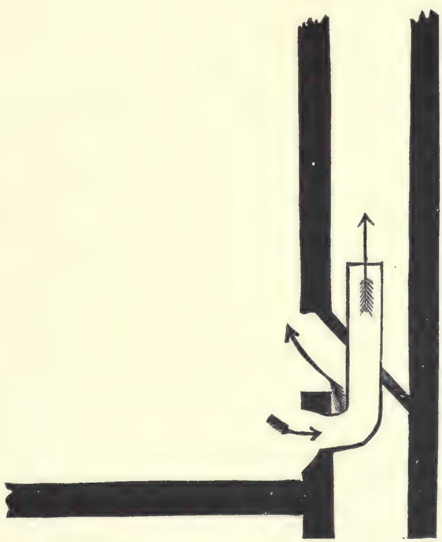


FIG. 56.

attempt to introduce fresh air from the door, windows or walls was useless. Large openings were made in the ceiling and roof, and above the opening in the roof a shaft was erected, divided by a partition and covered by a roof, large enough to prevent the intrusion of wind or rain. The result was entirely satisfactory and there was no discomfort. Dr. Radcliffe thinks that much of this satisfactory result was due to the fact that the ventilating tubes did not communicate directly with the room, but with the attic, which formed an air chamber, the ceiling acting as a diaphragm between this chamber and the room.

The inlet and outlet are combined in connection with the heating apparatus in what is known as Barker's patent. In this system the hot-air and the foul-air registers are in one frame, the former being above the latter. The lower part of the foul-air flue thus passes through the upper or terminal portion of the fresh-air flue by which it is warmed (Fig. 56).

The results obtained by this system in a ward of a hospital in Philadelphia, I have found to be not satisfactory. In cold weather a strong current is developed in the outlet flue, but the distribution of air within the room does not seem satisfactory; while with the external temperature of 50° F., the hot-air supply is in great part shut off to prevent overheating.

One of the many fallacies and errors which have from time to time been urged by writers on ventilation, and with which it is desirable that the architect and sanitary engineer should be acquainted, since they are constantly coming up afresh in the form of a patent or of a letter of advice to the daily press, is that of the effect of syphons or syphon-like arrangements as exit flues for foul air, and of the effect of Archimedean screw ventilators.

A pamphlet has appeared entitled "Ventilation by Means of the Patent Pneumatic or Air-Syphon with or without Artificial Heat," which begins as follows:

"The process does not require a fire, or any other artificial heat, or moving power. It consists of the practical application of operations constantly taking effect in the atmosphere, which cause a current to take a place through an inverted syphon, having one of its branches considerably longer than the other (whether it be in the open air or with the shorter branch communicating with a room or other place), into which the air enters at the orifice of the short branch, and is discharged by that of the longer. This process is not prevented by making the short branch hotter than the long. When it is proposed, in the hereafter-described arrangements, to use the chimney as the long branch, it is because of there being such a channel at hand, and because it is capable of serving a double purpose when the season requires fire, and is conveniently available for that single purpose (ventilation) when fire is *not* required."

Upon this absurd claim it is only necessary to remark that if a syphon could of itself either create or increase a current of air, the problem of perpetual motion would be solved, and man would be able to create force.

If there is a current of air in a syphon, it is because some force is producing it, and in the great majority of cases this force is due to a difference in temperature between the bodies of air at the extremities of the tube.

With regard to the various forms of Archimedean screw ventilators, as usually made they have no effect, unless driven by power independent of the wind. In calm weather, of course, all forms of cowls are entirely inoperative, except as furnishing more or less obstruction to the free egress of air; and on a still, warm day, when the temperature within a large building may be several degrees lower than that out of doors, there will be a tendency to a reversal of the current and to down draughts through any form of cowl that can be devised.

It often seems to be supposed by those advocating the use of this or that particular cowl, that the cowl itself has some mysterious effect in producing currents of air within it independent of wind or of differences of temperature, and that, therefore, if enough cowls are provided we can make sure of the effect desired under all circumstances. This is, of course, not the case, nor does it by any means follow that the use of two or more cowls on a building will produce more effect than one; in fact, the effect may be just the reverse. For example, I have seen a large three-story building in which the foul-air flues from the several floors terminated in the open space of the attic, and then half a dozen patent cowl ventilators were placed in the roof to complete the arrangement. The result was that the several cowls pulled against each other, and as they were only 9 inches in diameter, the result was sometimes almost inappreciable. Had a single shaft, about 3 feet in diameter and properly capped, been inserted, much better results would have been obtained, although this plan of using the whole attic as a foul-air reservoir is one that should be condemned under all circumstances.

CHAPTER XIII.

VENTILATION OF MINES.

IN the preceding chapters have been stated the general principles which should govern arrangements for ventilation, and we may now proceed to consider some of their practical applications. Among these, one of the greatest importance is that of the ventilation of mines, and especially of coal mines. In these the problem is not complicated by the need for varied quantities of artificial heat at different seasons of the year, which forms such an important feature in the arrangements for ventilation of dwellings, but, on the other hand, the mechanical problems are usually more complicated and difficult and the details require constant readjustment.

In many coal mines it is absolutely necessary to provide special ventilation, in order to prevent explosions from fire damp, but it should be supplied in all mines for the sake of the health of the men and animals employed in them. In the so-called fiery mines, where abundant and constant ventilation is necessary to prevent accidents, the health of the workmen is as a rule better than in those mines, whether of coal or of metal, where such abundant supply of fresh air is not given because it is not compulsory.

The earliest method of forced ventilation of a mine shaft or gallery, appears to have been by "the diligent shaking of a piece of cloth" as described and figured in the treatise of George Agricola, a copy of whose plate is given in Fig. 57, *A* being the level and *B* the cloth shaken by two men.

The air of mines is rendered impure by the products of respiration and other exhalations of the men and animals employed in them, by the products of combustion of candles or lamps, by the gases evolved from the surfaces of the mine or entering through fissures, including more especially carburetted hydrogen, carbonic acid, and sulphuretted hydrogen, and by dusts, which may be directly poisonous as in the case of arsenic or mercury, or may be mechanically injurious as in the case of coal dust, or of smoke from powder blasts. The gas which has been of chief importance in promoting mine ventilation is carburetted

hydrogen, CH_4, known also as marsh gas, fire damp, methane or methyl hydride, and is found chiefly in coal mines, although it has also been met with in salt mines. It is, as a rule, more abundant in deep mines than in shallow ones, and in European than in American mines. It is supposed to exist in a state of tension in the pores of the coal, and escapes from the fresh surfaces exposed in working. If

FIG. 57.

abundant, it escapes with a hissing or bubbling sound, and such coal is called "singing coal." It also collects under pressure in fissures in the coal, which when large are known as "blowers." After an exposed surface of coal has stood for a few days the evolution of fire damp greatly diminishes or ceases, and hence, in a mine which produces this gas the quantity given off depends to a great extent on the

amount of fresh surface daily exposed, and thus is proportional to the daily output. When mixed with atmospheric air in proportions of from 1 to 7 to 1 to 12, it forms a violently explosive mixture which, when fired, suddenly expands to 1,700 times its former volume, or, if confined may produce a pressure of 200 pounds to the square inch, with a rise of temperature to over 1,200° F. The result of such an explosion is not only the shattering and burning of objects in the vicinity, but the production of a mixture of carbonic acid, nitrogen and watery-vapor known as the after damp which is irrespirable and fatal to animal life. It is lighter than atmospheric air and hence rises to the upper part of galleries and pits. It does not begin to affect the flame of a lamp, to "show," as the miners say, until it forms about 3 per cent. of the mixture with air, hence it is often present to nearly that amount in the air inhaled, but nothing is known as to the effects produced by breathing air containing from 1 to 2 per cent. of it, and they are, at all events, not soon perceptible.

One of the first questions to be settled in planning for the ventilation of a given mine is the quantity of air required, and, unlike buildings, this cannot be determined once and for all, but must change with the progress of the work. In some of our States the minimum quantity is fixed by law, in relation to the number of men and animals employed in the mine, the quantity specified being usually 100 cubic feet of air per minute per man. In Pennsylvania 200 cubic feet per minute per man are required. In Colorado and Kentucky the law requires that for each mule or horse 500 cubic feet per minute must be furnished, and in Illinois and Washington, 600 cubic feet to each animal are required.

This mode of estimating the quantity of air required to maintain health and the combustion of the lamps, although useful as a basis for calculations, is entirely inadequate to give the real needs of a given coal mine in which fire damp either is being, or may be expected to be given off. To prevent accidents, the quantity of air must not only be sufficient to prevent perceptible odors, but it must be sufficient to dilute the fire damp so that the mixture will produce no visible effect on the flame of a lamp, and hence the more of this gas given off in a mine, the more air must be supplied. The amount of gas given off increases, other things being equal, with the amount of fresh surface of coal exposed, and this varies with the daily output, hence the rule sometimes referred to that from 100 to 200 cubic feet of air per minute should be furnished for every ton of coal extracted daily.

In a paper read before the Society of Engineers by Mr. George G. André, the quantity of air required for a dry mine making comparatively little gas is fixed at 1 cubic foot of air per second for every 100 square yards of surface. This, being the minimum amount, he states is analogous to the breaking strain of materials and must be multiplied by a factor of safety which will vary from 2 to 6. If there is comparatively little fire damp, and the mine is not very wet, he takes the factor of safety at 3, his mode of calculation being as follows: "Suppose we have to ventilate a mine in which the air courses have a total length of 2,000 yards, giving a total surface of, say, 14,000 square yards, and that the number of men and horses are 100 and 10, respectively;" he allows to the men a cubic foot for respiration, a cubic foot for the removal of perspiration, and a cubic foot for his lamp, or, in all, 3 cubic feet per minute; while for the horses he allows 12 cubic feet per minute. The men and animals in this mine will then require 420 cubic feet per minute, and the vapors, gases, etc., will require 140 cubic feet per second, or 8,400 cubic feet per minute, $(8,400 + 420) \times 3 = 26,460$ cubic feet per minute as the adequate amount of ventilation. While the allowance of air for men and animals is absurdly small yet a large part of the air which is allowed for the other purposes will serve for their consumption, and hence the practical outcome of this estimate would be probably a very good one if the mine was not a fiery one.

The formula given by Bagot is as follows:

Q = quantity of air in cubic feet to be supplied per minute.

M = number of men at work in the mine.

H = number of horses at work in the mine.

P = pounds of gunpowder fired per hour.

O = tons or cubic yards of coal raised per minute.

A = square yards of area of surface coal exposed to the ventilating current.

Then $Q = 24 M + 72 H + 192 P = 100 O + A$.

Thus, in a mine with 400 men, 30 horses, output of 600 tons per day, using 8 pounds of powder per hour, and having a coal surface of 1,000 yards:

$Q = 400 (24) + 30 (72) + 8 (192) = 17\frac{2}{3} (100) + 1,000 = 16,062\frac{2}{3}$ cubic feet per minute.

This formula is entirely inadequate even for a mine that is not fiery, for it would give to each man only about 40 cubic feet per minute, while 80 cubic feet per minute should be the minimum allowance per man in a metal mine and 100 cubic feet per minute in a coal

mine producing little gas, while for fiery mines it is necessary to provide air ways and fans capable of increasing this quantity from three to six times as occasion demands.

As the mine is extended and becomes deeper, the quantity of air required increases if the number of men and the output remain the same, because some air is required to keep those parts of the mine which have been worked, free from accumulations of gas so long as they are not entirely abandoned and closed off from the working part of the mine by a close and continuous wall. The quantity of air required in different parts of a coal mine, and especially of a fiery mine, varies from day to day and must be adjusted by daily observations of the proportion of fire damp present made by skilled men each morning before the workmen go in for work.

Having fixed on the amount of air to be supplied, the next thing is to settle on the means to be used for moving the air, bearing in mind that it is not only present or immediate wants that are to be provided for, but that as the mine extends the amount of air required will become greater, and the friction will increase, requiring more force.

To secure ventilation in a mine it must have at least two distinct openings, each communicating with the outside air. If now the air in the mine becomes lighter, volume for volume, than the superincumbent atmosphere, by becoming heated—by mixture with fire damp—or, by the addition of vapor of water, the tendency is to produce a current flowing out of one opening and into the other. If the openings are at different levels the current will enter at the lower opening and pass out at the higher one in winter, while the reverse would occur in summer, unless the temperature of the mine exceeds that of the external air. The current thus produced will be usually feeble, and it would only be in a small mine, with large shafts and galleries, and few workmen and lights, that this natural ventilation would be sufficient, and it will necessarily be irregular and vary with the season, time of day, etc., because it depends mainly on difference of temperatures. It is especially liable to be defective in warm weather.

Artificial means of ventilation for a mine consist either of means of heating the air in one of the shafts, or of some form of fan to force the air to move in a particular direction.

The heating of the air in an upcast shaft, by means of a furnace, has been and still is extensively employed in mine ventilation, but in mines giving out much fire damp it is being superseded by the fan, and in such mines its use is forbidden by the Pennsylvania law.

If a furnace be used to ventilate a fiery mine, special precautions are necessary to prevent the air of the mine from coming in contact with the flame of the furnace—and for this purpose it may even be necessary to bring the air required to support combustion through a separate channel from the outer air. Where there is no fear of any explosive mixture, and the upcast shaft can be used solely for ventilation, the air of the mine can pass directly through and over the furnace, which should be in a gallery near the bottom of the shaft, or in a space excavated for the purpose.

The furnace costs less than the fan to construct, and its work is not so liable to be interrupted for repairs, while even if it does stop for an hour or two the heated shaft will still continue to act. On the other hand, it consumes much more fuel than would be required to run a fan to do the same work, and requires large passages, since it cannot work against much friction.

Callon says that "in practice it is usually sufficient to raise the temperature of the air that has passed round the workings from 20° to 40° F., so that the column of heated air in the upcast has not a higher temperature than 100° to 115° F. In these conditions of temperature the upcast shaft may, if necessary, be used even as a winding pit, provided that wire ropes are employed in it. It ought not to be made use of for pumping, however, because a pumping shaft is always very wet, and drops of water falling down are hurtful to the ventilation, since they cool the ascending air."

According to Ramsay, "The maximum power of a furnace by rarifying the air appears to be about 1,000 cubic feet per minute per foot area of the upcast shaft, with a density of between 2 and 3 inches of water-gauge."

Furnaces are used chiefly in English mines, while fans are preferred in France, Belgium and America. Ventilating fans for mines may be either propelling or exhaust; but as a rule the exhaust fans are used.

Figure 58 is a copy of a plate given in the work of Agricola, published in 1556, to show the various kind of fans then used or proposed for mine ventilation. One specimen is shown with a square case and one with a round one.

He says that these fans may be driven by a windmill, but as there is often no wind these are less useful than those which can be turned by hand.

Figure 59 shows the construction of some of these fans.

It is a long step from these quaint old patterns to those of the present day.

FIG. 58.

A, circular-case fan. *B*, square-case fan. *C*, air inlet. *E*, wooden air ducts. *H*, weights at ends or rods acting like a fly-wheel.

The fan that is now most used in mine ventilation is the Guibal fan with various modifications, and of diameters varying from 15 to 30 feet, although there are several in use of diameters of from 35 to 50 feet. It is difficult to obtain reliable data as to the efficiency of different forms and sizes of fans used in mine ventilation, or as to their relative economy in working, because no two mines are alike in

FIG. 59.

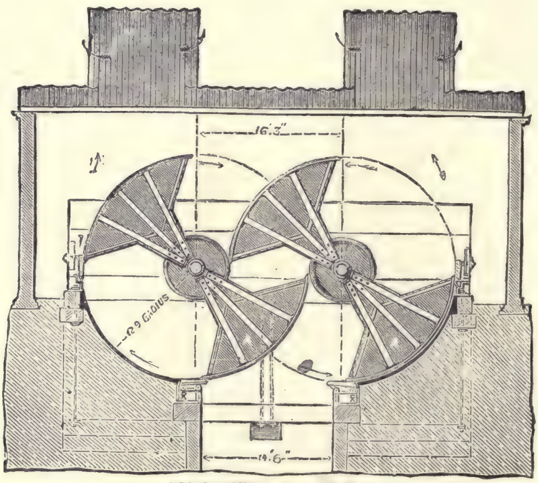
A, fan made of boards. *B*, one having the blades made of overlapping plates of thin wood. *C*, fans made with goose feathers. *D*, central portion of shaft. *E*, axle. F, handle.

the amount of friction presented to the air currents which traverse them, and, therefore, in the amount of force required to move a given quantity of air through them, and in fact, the same mine will differ in this respect in successive months.

The best collection of data on this subject which we have seen is contained in a paper by R. Van A. Norris, of Wilkesbarre, Pa., on "Centrifugal Ventilators," read before the American Institute of Mining Engineers, in October, 1891. From this it appears that a double

Guibal fan, 20 feet in diameter and 6 feet wide, running at 100 revolutious per minute, removed 3,369 cubic feet of air per revolution, working against a resistance equal to 2½ inches of water gauge, and that a Guibal fan, 35 feet in diameter and 11′ 8″ wide, at 46 revolutions per minute, removed 4,975 cubic feet per minute with a water gauge of 1.95 inches.

The preference appears to be given to fans of from 18 to 25 feet in diameter. Simplicity and strength of structure in a fan and its connections, so as to do away, as far as possible, with all danger of accidental stoppage, are most important, for in a fiery mine 10 minutes stoppage of the fan may mean death to the miners.



CROSS SECTION OF VENTILATOR

FIG. 60.

Large fans, including all over 20 feet in diameter, running at comparatively low speeds, move large quantities of air provided the supply comes to them freely—that is, if the galleries are large and the manometrical depression low, but lose much of their efficiency if they have to work against high resistances. In this last case some form of blowing machine in which a definite volume of air is taken in and delivered in a given time at a given speed, irrespective of the resistance, may be preferred, since the increase of power for increase of resistance can be calculated and provided for. These include such machines as Fabry's and Lemielle's ventilators and Root's blower. Figure 60 shows a cross-section of the Root's blower used at the Chilton colliery, Ferryhill, Eng.

Each of the rotary pistons is 25 feet in diameter and 13 feet wide, the sides being covered with wood and the ends with sheet iron. The calculated capacity is 5,800 cubic feet per revolution.

The distribution of the air is a matter of great importance in mine ventilation, especially in coal mines. The fresh air should be delivered with as little loss and contamination as possible at the face of the workings, that the men may have the benefit of it and so that if an explosion does take place it shall not cut off their air space. To effect this it is necessary to direct the incoming current of air to follow a given course, providing a separate and distinct passage for it, to divide it at certain points, carrying a part in one direction and a part in another in quantities proportional to the amount required at the different termini, and to take it into shafts and galleries which are in process of construction and in which, therefore, temporary provision must be made for two channels, one for the incoming and the other for the outgoing air. This isolation of the currents is effected by the use of partitions which may be permanent walls of the natural rock left for the purpose, or walls built for the purpose, or wooden or cloth partitions, or special air ducts of wood or iron. As the works advance these brattices or partitions should be provided, and it is to neglect of this until the air at the face of the work becomes so foul that the brattice becomes an absolute necessity, that a considerable part of the ill health of the men and of danger from fire damp is due. It is in the adjustment and constant supervision of these partitions to meet the changes of work in the mine, to secure the separation of the air currents without interfering with transport, and in doing this with the least friction and resistance to the movement of the air, that the knowledge and practical efficiency of the engineer or superintendent is especially manifest. It must be constantly borne in mind that the larger and more direct the channels through which the air moves the less power is required to move it, and the greater therefore is the efficiency of the fan or other motive power employed for that purpose. The galleries should be as large as the cost of their construction and maintenance will permit, and their section should be as uniform as possible to avoid eddies. The return air ways should be at least as large as those for supply, and it is better that they should be larger because the volume of the incoming air is increased by leakage of gas from the rock and by increase of temperature.

Where the disposal of fire damp is an important object, the fact that this gas is lighter than air and tends to rise above it when pure, makes it important that the return-current should be upward and

The following table shows the effects of fan ventilation in certain mines in Third Pennsylvania Anthracite District as taken from the official reports:

Mine.	Location.		Mode of Ventilation.	No. of Fans.			Men Employed in the Mines by Day.				Cubic Feet of Air per Minute at Inlet.				Cubic Feet of Air per Minute at Outlet			
				1888.	1889.	1890.	1888.	1889.	1890.	Average	1888.	1889.	1890.	Average	1888.	1889.	1890.	Average
Hollenbeck...	Wilkesbarre	Lehigh and Wilkes-barre Canal Co.	Fan	2	2	2	337	178	108	207	313,000	325,270	367,565	335,278	315,800	338,400	367,307	340,502
Empire	"		"	1	2	2	441	480	469	463	228,000	147,896	253,410	209,768	190,950	169,142	233,330	197,807
Stanton......... ...	"		"	2	3	3	313	320	54	229	200,800	181,250	106,800	162.950	230,556	247.400	262,300	246,752
No. 9 shaft.	"		"	2	3	3	353	229	197	259	270,700	246,100	296,000	270,933	3,1,280	261,240	307,300	303,273
Lance No. 11..... ..	Plymouth		"	1	1	1	352	292	153	265	178,220	162,240	120,240	153,566	191,420	183,540	170,900	181,953
Nottingham No. 15	"		"	2	2	2	646	691	636	257	208,850	198,870	194,285	200,668	218,000	201,600	196.780	205,460
Reynolds No. 16...	"		"	1	1	1	338	295	230	287	93,300	92,800	84,200	90,100	91,700	94,300	86,200	90,733
No. 3 Plymouth...	Plymouth To.	Del. & Hudson Canal Co.	"	1	1	1	295	110	168	191	68,800	44,210	68,725	60,578	69,800	45,310	86,750	67,287
" 5 " ...	" "		"	2	1	2	287	205	186	226	122,000	110,000	113,000	115,000	124,000	112,000	115,600	117,200
" 2 Slope . ..	Nanticoke	Susquehanna Coal Co.	"	2	2	2	231	224	239	231	123,500	121,500	120,000	121,666	132,500	126,500	122,500	127,166
" 4 "	"		"	2	2	2	265	215	132	204	186,210	119,170	202,933	169,437	187,260	130,600	201,570	173,143
" 6 Tunnel......	Glen Lyon		"	1	1	1	188	132	76	132	81,425	72,865	118,582	90,957	81,165	71,040	116,440	89,548
" 1 Shaft........	Nanticoke		"	2	2	2	199	215	268	227	131,684	97,305	102,142	110,343	206,464	105,879	115,614	142,652
" 2 "	"		"	3	1	1	391	193	171	251	152,200	67,880	64.850	94,976	171,046	73,350	68,450	104,282
							4,636	3,779	3,087	3,834	2 358,689	1,987,356	2,212,732	2,186,259	2,551,941	2,160,301	2,451,041	2,387,761

never downward; in other words, the fresh air should be delivered at the lowest part of the workings.

When the fire damp has once become mixed with air the law of the diffusion of gases prevents their separation and the mixture must move as such. As the workings get lower, what was at first a fresh-air gallery may become a return-air passage.

In the ventilation of large mines the resistance to the movement of the air due to friction of surfaces of galleries, and to eddies produced by abrupt turns or sudden expansions and contractions of ducts is often very great, and a large part of the power employed to produce air currents is needed to overcome this resistance.

The amount of friction depends on the size and length of the galleries, the number and character of the angles through which the current must turn, and on the velocity of the current, hence it is not the same in different mines, nor in the same mine at different times, the tendency being to its increase with the increase in the length and depth of the workings. It increases in direct proportion to the area of rubbing surface and as the square of the velocity of the current. The average co-efficient of friction in mines is given by Atkinson* as being 0.0217 pound per square foot of rubbing surface with a velocity of the air current of 1,000 feet per minute. If the velocity of the current is only 1 foot per minute the co-efficient of friction becomes 0.0000000217 pound.

For any given gallery the formula is $p\,a = k\,s\,v^2$, in which p = pressure per square foot of area, a = sectional area in square feet, k = co-efficient of friction, s = rubbing surface, and v = velocity of the current in thousands of feet per minute, 1,000 feet per minute being counted as 1.

In mining engineering the pressure in pounds per square inch required to impart a given velocity to a column of air is often called the "head of air," because in using furnaces it was calculated as the difference in height of two columns of air of equal weight, but of different temperatures. The total resistance to the flow of air due to friction, eddies, etc., in any given system of air circulation may be represented as the resistance which would be given by an orifice of a certain size in a thin plate, for a certain head of air, which may be called the resistance of the mine. If the head of air—or briefly, the head, be stated as the number of foot pounds of force required to drive a pound of air through a given orifice, and the orifice be taken

*A practical treatise on the gases met with in coal mines, etc, London, 1889, p. 37.

as having the area $k\,a$—a, being the area in square feet, and k the co-efficient of contraction, usually taken as 0.65, then the volume of air in cubic feet passing is equal to the square root of the head divided by the resistance of the orifice, or $H = \frac{V^2}{27\,a^2}$.

The friction, and the power required to overcome it, increases very rapidly as the velocity of the currents increase, hence they should be as slow as is compatible with furnishing the amount of air required. They should not anywhere exceed 8 feet per second, to avoid dangerous dusts and bad effect on lamps, and 5 or 6 feet per second is much preferable. But with reduced velocities larger air ways are needed and none of the fresh air must be wasted, hence an important feature in the practical adjustment of the ventilation of a mine is the division of the entering current of air in such a way as to send different amounts to different parts of the mine in proportion to their needs, and diminish friction by increasing the area of the air passages, and thus permitting the required quantity to pass at a lower velocity. In this "splitting the current," as it is termed, each split takes fresh air directly from the main inlet, and thus delivers air which has not passed through other workings.

The amount of air passing through a given opening or gallery is determined by anemometrical measurements, and the pressure under which it is moving is ascertained by a form of manometer known as the water gauge.

The following is a list of a few of the most important works on mine ventilation:

1. Appendix "B" to Report of the Commissioners appointed to Inquire into the Condition of All Mines in Great Britain. 406 pp., fol. London: 1864. This contains valuable data on the air of mines by Drs. Taylor, Angus Smith and Bernays, and with this should be compared those given in a valuable paper on the air of coal mines by Mr. Nasmyth, published in the *British Medical Journal* of August 4, 1888, p. 222.

2. Lectures on Mining. By J. Callon; translated; Vol. II., Chapter XX. 8vo. London: 1881.

3. A Treatise on Ventilating and Working Collieries. By J. A. Ramsay, M. E. London: Longmans & Co., 1882, pp. 41.

4. The Principles of Colliery Ventilation. By Alan Bagot. 2d ed., 8vo. London: 1882.

5. A Practical Treatise on the Gases met with in Coal Mines and the General Principles of Ventilation. By J. A. Atkinson. 12mo. London: 1889.

6. A Treatise on Practical and Theoretical Mine Ventilation. By E. B. Wilson. 4th ed. New York: 1891.

CHAPTER XIV.

VENTILATION OF HOSPITALS AND BARRACKS. BARRACK HOSPITALS. HOSPITALS FOR CONTAGIOUS DISEASES. BLEGDAMS HOSPITAL. U. S. ARMY HOSPITALS. CAMBRIDGE HOSPITAL. HAZLETON HOSPITAL. BARNES HOSPITAL. NEW YORK HOSPITAL. JOHNS HOPKINS HOSPITAL. HAMBURG HOSPITAL. INSANE ASYLUMS. BARRACKS.

WE now come to the consideration of a class of buildings in which the subject of ventilation is specially important—namely, hospitals.

The necessity of providing these buildings with more than the usual means of ventilation has long been recognized, and in almost every large hospital which has been planned or built during the present century some attempt has been made to meet this demand. Yet, in spite of the experience thus gained, and of some careful studies by physicians, engineers and architects as to the relative merits of various systems, it must be confessed that the results obtained have too often been unsatisfactory.

The bad results of imperfect ventilation, or of an impure air supply, are more strikingly evident in hospitals than in other buildings, owing in part to their continuous occupation, in part to the lowered vitality of their inmates, who are specially susceptible to insanitary influences, and in part to the presence of special causes of disease in the form of germs or miasms. The great difficulty in providing a constant and sufficient supply of pure air to hospital wards, in such a way that at all hours of the day or night, at all seasons, or in all conditions of wind, they shall be free from all odor and comfortable for the patients, is not so much a want of knowledge of the means by which this may be effected as it is the expense which must be incurred, not only in providing the necessary construction and apparatus for heating and ventilation, but also to keep the system in operation after it has been provided. This expense is almost invariably underestimated, and those who have to furnish the funds for the support of the institution are disappointed

accordingly, and in attempting to reduce the cost are too apt to reduce the ventilation also.

The hospitals for which an architect is liable to be called on to prepare plans differ greatly in purpose, size and arrangement. Among the simplest are those intended for the reception of contagious diseases, the so-called pest houses. These are usually cheap temporary

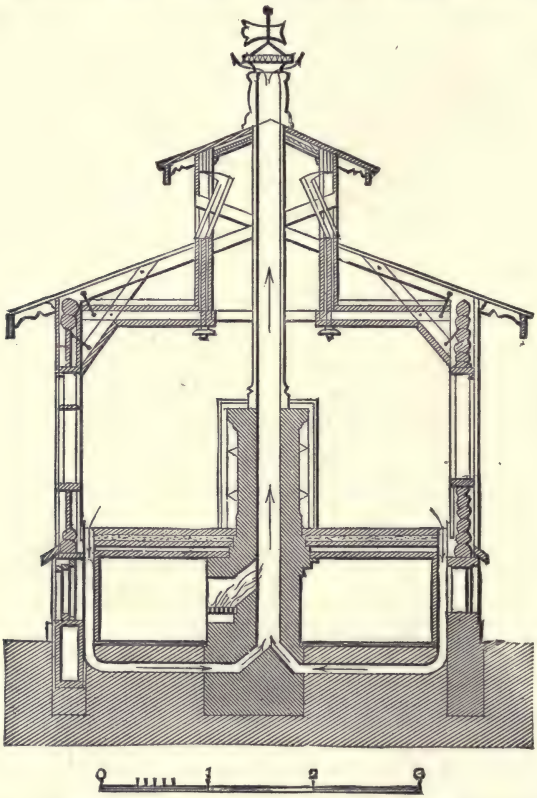


FIG. 61.—CROSS SECTION, ST. PETERSBURGH CITY HOSPITAL.

structures, hastily erected to meet an emergency, and the architect is rarely consulted with regard to them. It would be much better if he were, for such hospitals should be considered as an indispensable part of the municipal machinery of every city of 10,000 inhabitants and upward ; they should be carefully constructed while the emergency is yet afar off, and while they should be simple and cheap, they should

have a neat and attractive appearance, instead of looking, as they usually do, like enlarged dog kennels. Their ugly, box-like appearance can be done away with by a simple, broken, cottage-like outline, without much additional expense, and they will then be considered as worth taking care of. They will be one-story wooden buildings, with wards containing about six beds, heated by a stove in the center.

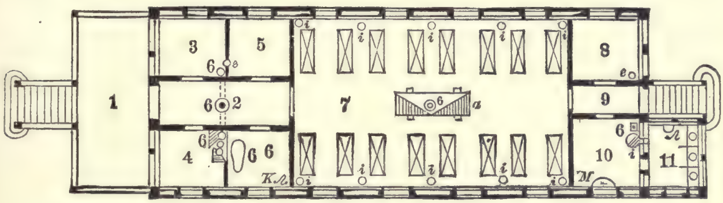


FIG. 62.—FLOOR PLAN OF ST. PETERSBURGH CITY HOSPITAL.

1.—Porch.
2.—Hall.
3.—Nurses' room.
4.—Ward kitchen.
5.—Room for two patients.
6.—Bath.
7.—Ward.
8.—Room for two patients.
9.—Hall.
10.—Wash-room.
11.—Water-closet.

Through or around this stove the greater part of the fresh air should be introduced in cold weather, while the foul air should be removed by a shaft reaching nearly to the floor near the stove, and containing the stove-pipe in its upper part. Upon a larger scale this kind of building is known as a barrack hospital, and excellent results have been obtained from it. To illustrate its possibilities, I give figures showing

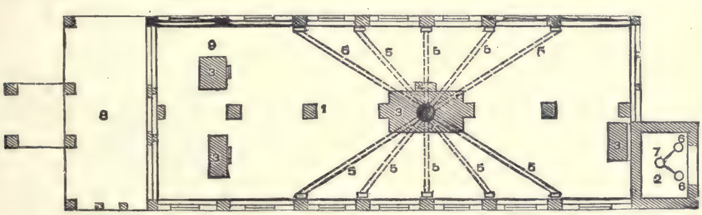


FIG. 63.—CELLAR PLAN OF ST. PETERSBURGH CITY HOSPITAL.

1.—Cellar.
2.—Soil pipes.
3.—Foundation of stone.
5.—Foul-air tubes beneath the floor.
6, 7.—Vessels for excreta.

plan and cross section of one of the barracks of the Roschdestwensky City Hospital, in St. Petersburgh (Figs. 61 and 62).

This hospital has three of these barracks, constructed in 1871–72, and they have proved to be a great success, being comfortably warm in the extreme cold of the Russian winter, and giving excellent results in cases of typhus and also in surgical cases.

The walls of this barrack are triple, inclosing two air spaces. The arrangement of the ward heating and ventilation is sufficiently shown in the figures. The great central German porcelain stove is 14 feet long, 4 feet 8 inches wide, and 6 feet high. This so-called stove is rather a furnace, fired from below, and has through it eight openings for the admission of fresh warm air into the ward. The foul-air flues open into the central smoke flue, as shown in the cross section. Besides this central stove, there are three others, and the whole furnish about 103,000 cubic feet of fresh air per hour. When the external temperature is not below the freezing point these stoves are fired but once a day. When between zero and 32° F., they are fired twice a day, and when below zero, three, and in extreme cold, four times a day. When I was in this ward in August, 1881, it was quite free from unpleasant odor, although it was filled with fever cases; the day was cold and raw, but the temperature of the ward was all that could be desired. It is an interesting hospital, as proving that even in the coldest climates such wards can be made perfectly comfortable and at the same time be kept well ventilated.

An interesting form of hospital ward for small-pox patients is shown in Figs. 64 to 67, which are prepared from illustrations published in *The Builder*. This hospital, recently constructed by the Corporation of Bradford, England, consists of two wards each 75x15 feet, placed back to back with a space of about 3 feet between them, forming a foul-air chamber from which the air is drawn by an aspirating shaft, and containing below a fresh-air chamber and heating surfaces. The windows are tight and the fresh air enters through the inlets *A A A* into the lowest compartment *G*, of the space between the wards. From this duct the air passes through flues *B*, and enters the ward through floor gratings at the foot of each bed. The foul-air registers are in the ceiling over each bed. All the foul air must pass through the furnace at the base of the aspirating shaft. For the English climate this will, no doubt, answer, but when the external air is at zero this is a very wasteful method of heating.

This plan of subjecting all the air escaping from a small-pox ward to high temperature is in accordance with a plan prepared several years ago by Dr. Burdon Sanderson, who proposed that each ward should be in the form of a ring, with the chamber from which the air is directly extracted in the center of the ring, and that for a ward of 12 beds, having a capacity of about 1,200 cubic feet per bed, the removal of air should be about 120,000 cubic feet per hour.

"The beds would be arranged as near as possible to and immediately below each extracting opening, and would be placed against the internal wall, and each bed would be placed between two of the septa or screens which pass to a certain distance out from the internal wall into the annular space, so that the head of each bed would be in-

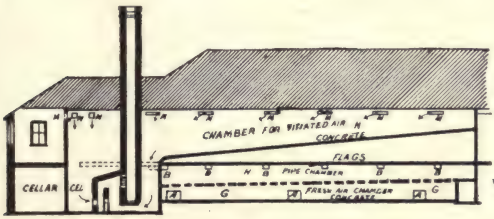


FIG. 64.

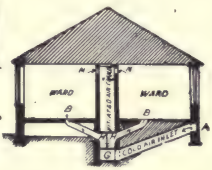


FIG. 65.

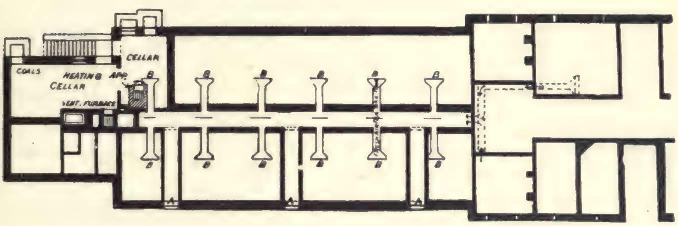


FIG. 66.

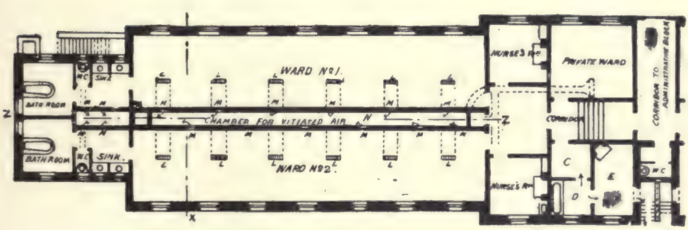


FIG. 67.

cluded in the space between each two neighboring septa. The space within the ring communicates with the annular space by extracting openings, and discharges the air into a chamber, where it could be subjected to a higher temperature, so as to destroy all organic matter it might contain."

The windows are not to open. Twenty-four openings for fresh air are to be made in the external wall, each having 2 square feet of area. The movement of air through the outlet openings is intended to be at

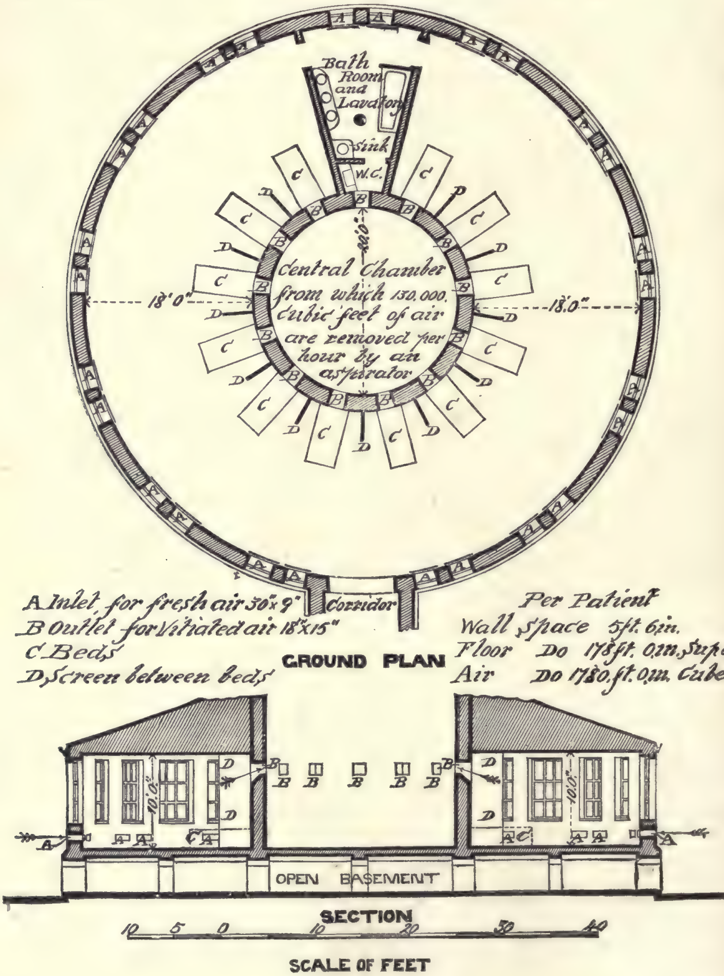


FIG. 68.

the rate of 1 mile per hour, allowing 10,000 cubic feet of air for each patient, and to secure this slow movement and thus prevent draughts, the outlet openings are also to be 2 feet square. The method of

warming proposed is to carry around hot-water pipes in front of the inlet openings. From the fan the air is to pass to a gas furnace, probably in the roof of the house.

From this description and the plans, of which copies are appended, it is evident that while it is theoretically possible to thus disinfect all the air passing through a small-pox ward, it would be at a relatively great expense. The circular ward is used in the new City Hospital at Antwerp, and the same principle is employed in the Octagon Ward of the Johns Hopkins Hospital, at Baltimore; but in both these the beds are arranged against the outer wall, having the heads toward the windows, which is a much more convenient way of arranging them than in the plan above proposed, both because it allows more space about each

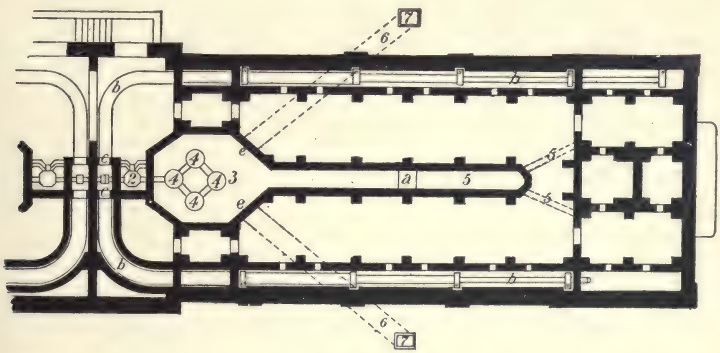


FIG. 69.

2.—Furnace.
3.—Fresh-air chamber.
4.—Heaters.
5.—Fresh-air duct from air chamber.
6.—Fresh-air duct to air chamber.
7.—Fresh-air inlets.
a—Fresh-air inlet.
b—Foul-air duct.
c—Point of entrance of foul-air duct to aspirating chimney.

bed and because it does not compel the patients to face the light, which would be extremely unpleasant in the acute stage of small-pox.

A second objection is that the central shaft is unnecessarily large, as are also the inlets into it. It is not desirable to reduce the velocity of the air at the outlets or in foul-air ducts below 4 or 5 feet per second, because at very low velocities a very slight thing will disturb the currents. The velocity at the outlet has comparatively little to do with the production of draughts.

These suggestions are made, not for the purpose of fault-finding, but because everything which comes from such distinguished authority should be made as perfect as possible.

It seems probable, however, that the neighborhood would be more certainly and economically protected by the continuous enforcement of vaccination than it would be by any particular form of hospital.

Another arrangement of a ward for infectious diseases is shown in Figs. 69, 70 and 71, which give the basement and floor plans, and longitudinal section of such a ward in the Blegdams Hospital, in Copenhagen.

If an isolating ward is to receive several different kinds of contagious or offensive disease it must be divided into as many distinct divisions, each having entirely separate ventilation. In the isolating

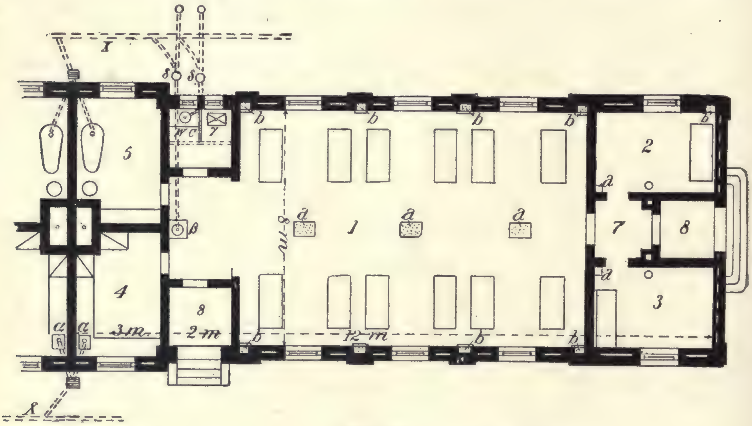


FIG. 70.

1.—Ward.
2.—Isolation ward.
3.—Nurse.
4.—Kitchen.
5.—Bath-room.
6.—Water-closet.
7.—Corridor.
8.—Lobby.

a—Inlet openings for fresh air.
b—Aspirating openings for vitiated air.
c—Chimney.
B—Wash-stand.
Y—Sink
S—Interceptor.
X—Sewer.

ward of the Johns Hopkins Hospital there are rooms on either side of a central corridor, which corridor is freely open to the outer air. Each room has an open fireplace with a separate flue, placed in the center of the inner wall of the room. On one side of this chimney is the entrance to the room from the corridor, closed by double doors; on the other side is a small closet containing a commode, the chamber from which can be removed through an opening in the wall without entering the room. This closet is lined with galvanized iron and has a separate exit flue in which is an accelerating steam coil. The door of this closet does not come to the floor by 4 inches and the exit of the air, which enters the room through large openings in the outer wall, is mainly

through this closet and up its special flue which is of iron so that the whole can readily be cleansed with flame.

A longitudinal section of this ward is shown in Fig. 72, a longitudinal section of the inner wall of one of the rooms is shown in Fig.

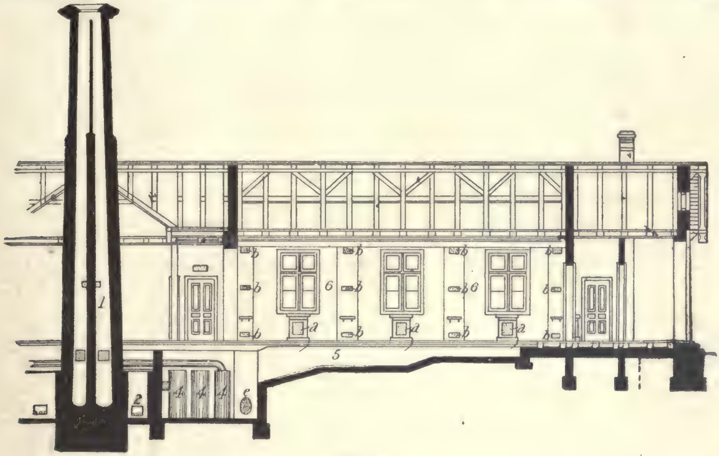


FIG. 71.

1.—Chimney.
2.—Furnace.
3.—Fresh-air chamber.
4.—Heater.
5.—Fresh-air duct
6.—Ward.

a—Inlet openings for fresh air.
b—Aspirating openings for vitiated air.
c—Inlet of aspirating duct in chimney.
d—Outlet opening in chimney for vitiated air from closets.
e—Inlet opening for fresh air in air chamber.

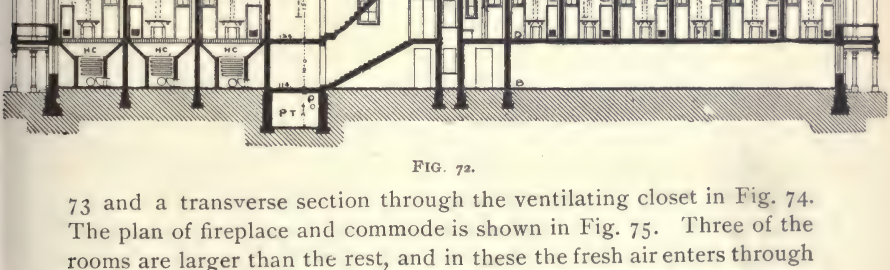


FIG. 72.

73 and a transverse section through the ventilating closet in Fig. 74. The plan of fireplace and commode is shown in Fig. 75. Three of the rooms are larger than the rest, and in these the fresh air enters through the floor, which for a distance of 7 feet from the outer wall is perfor-

ated with ¼-inch holes, there being 5,000 such holes in each room The heaters for these rooms are marked *H C* in Fig. 72, and are shown on a larger scale in Fig. 76.

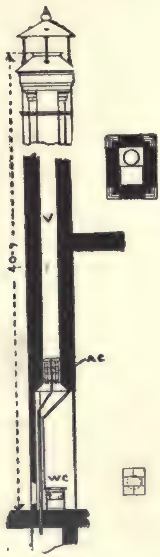


FIG. 73.

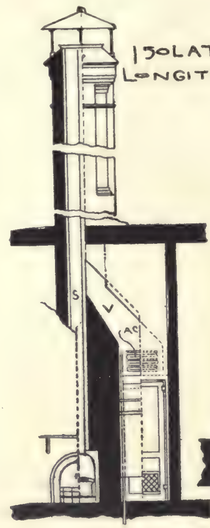


FIG. 74.

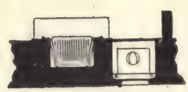


FIG. 75.

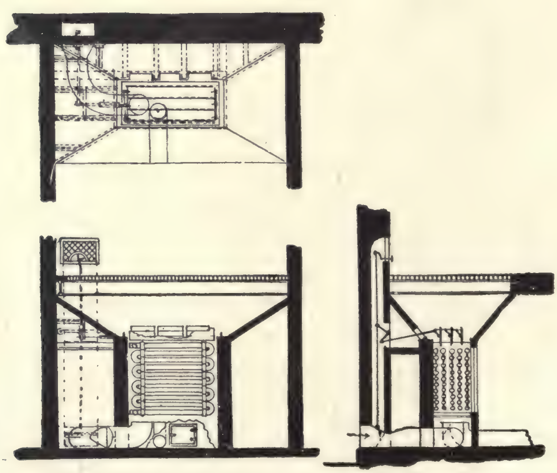


FIG. 76.

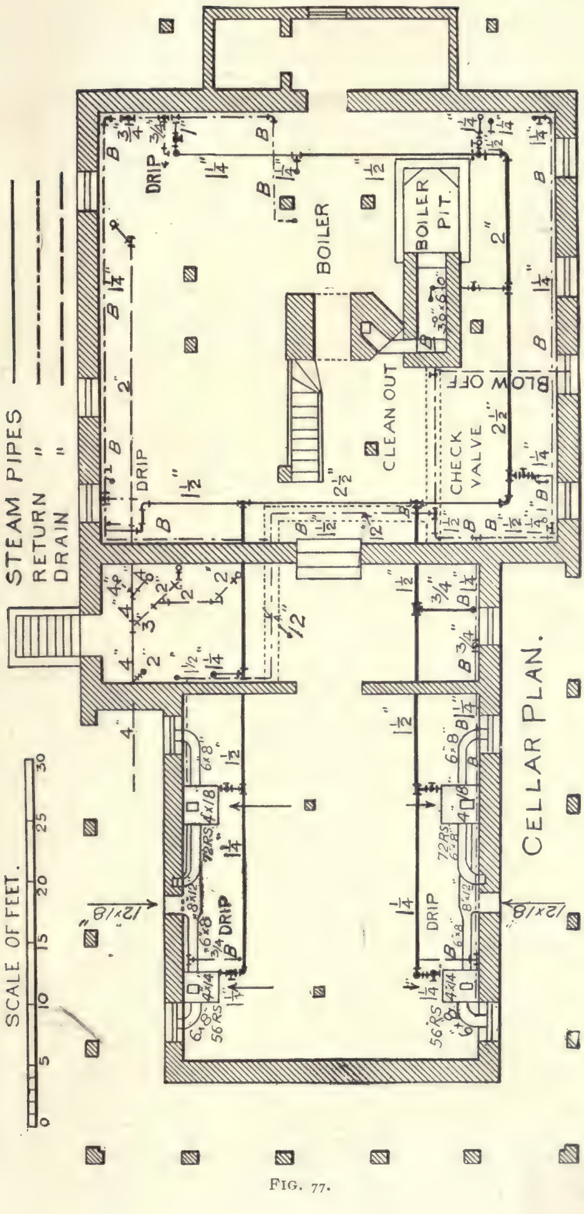

STEAM PIPES
RETURN " "
DRAIN " "
BOILER
BOILER PIT.
CLEAN OUT
CHECK VALVE
BLOW OFF
DRIP
CELLAR PLAN.
SCALE OF FEET.
0 5 10 15 20 25 30

FIG. 77.

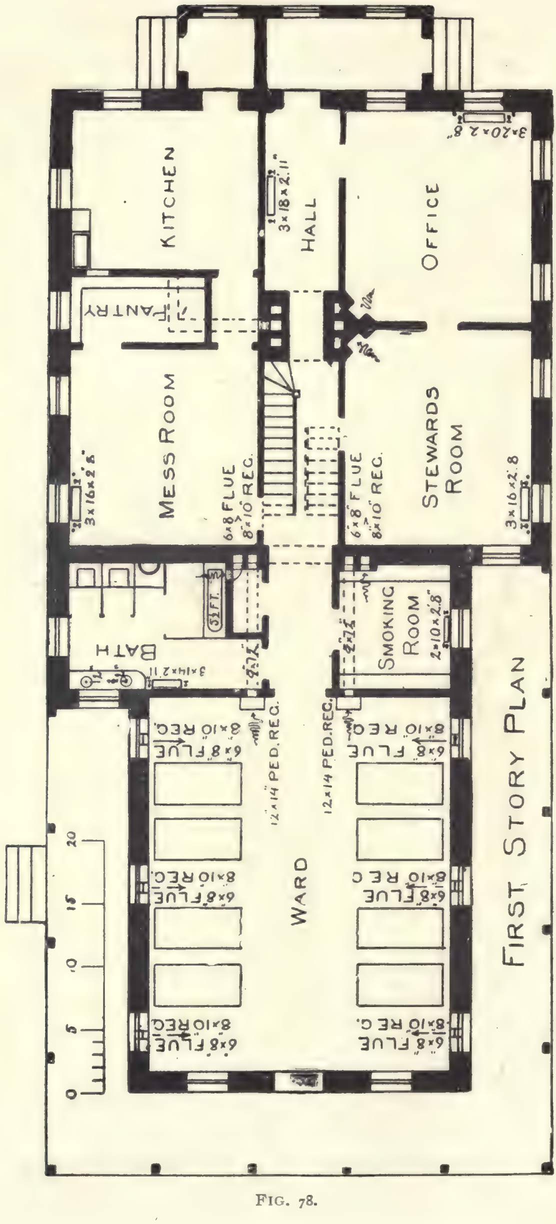

KITCHEN
HALL
3×18×2.11"
OFFICE
3×20×2.8"
PANTRY
MESS ROOM
3×16×2.8"
6×8 FLUE
8×10 REC.
STEWARDS ROOM
3×16×2.8
BATH
3×14×2.11
SMOKING ROOM
2×10×2.8"
12×14 PED.REC.
8×10 REC.
6×8 FLUE
WARD
FIRST STORY PLAN
0
5
10
15
20

FIG. 78.

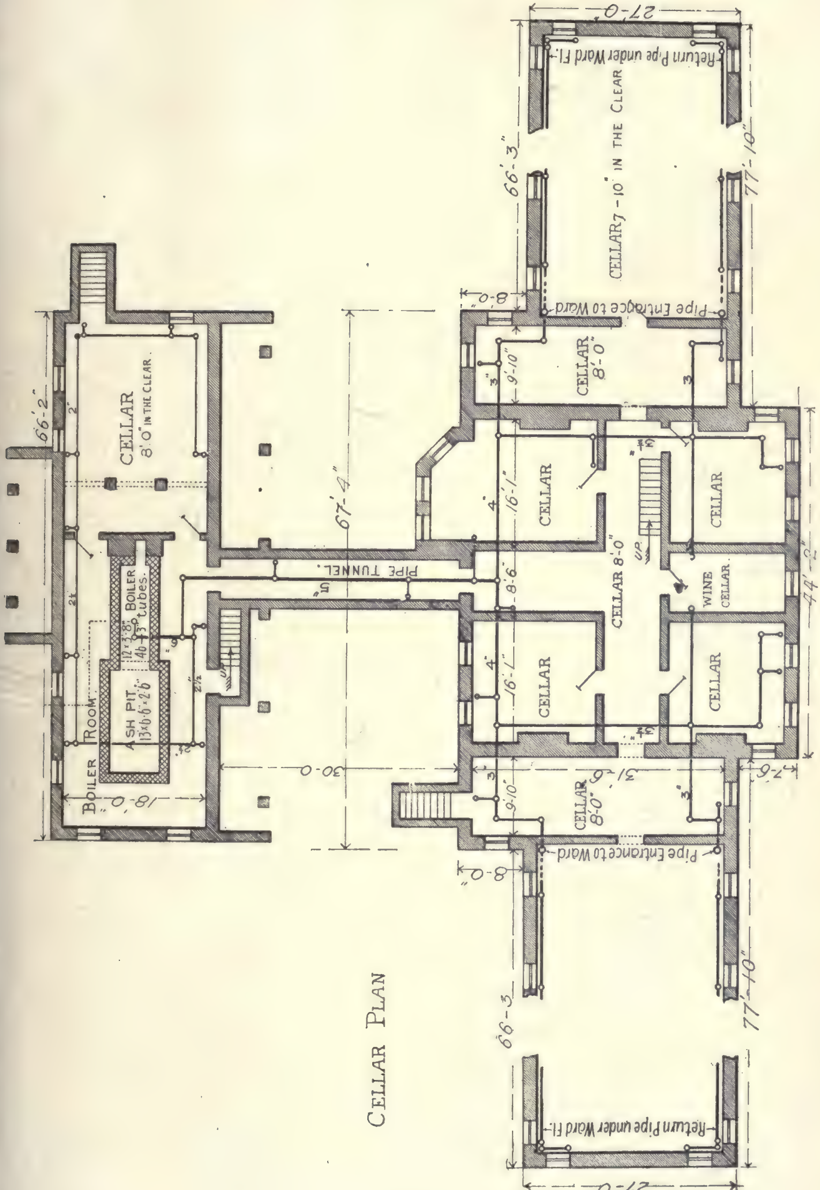

CELLAR PLAN
CELLAR 7'-10" IN THE CLEAR
Return Pipe under Ward Fl.
Pipe Entrance to Ward
CELLAR 8'-0"
CELLAR 8'-0" IN THE CLEAR
BOILER ROOM
ASH PIT 13×6·6×2·6
BOILER 12×3·8 40-3" tubes.
PIPE TUNNEL
CELLAR
WINE CELLAR
UP
27'-0"
66'-3"
77'-10"
66'-2"
67'-4"
44'-2"
31'-6"
30'-0"
18'-0"
16'-1"
9'-10"
8'-6"
8'-0"
7'-6"

FIG. 79.

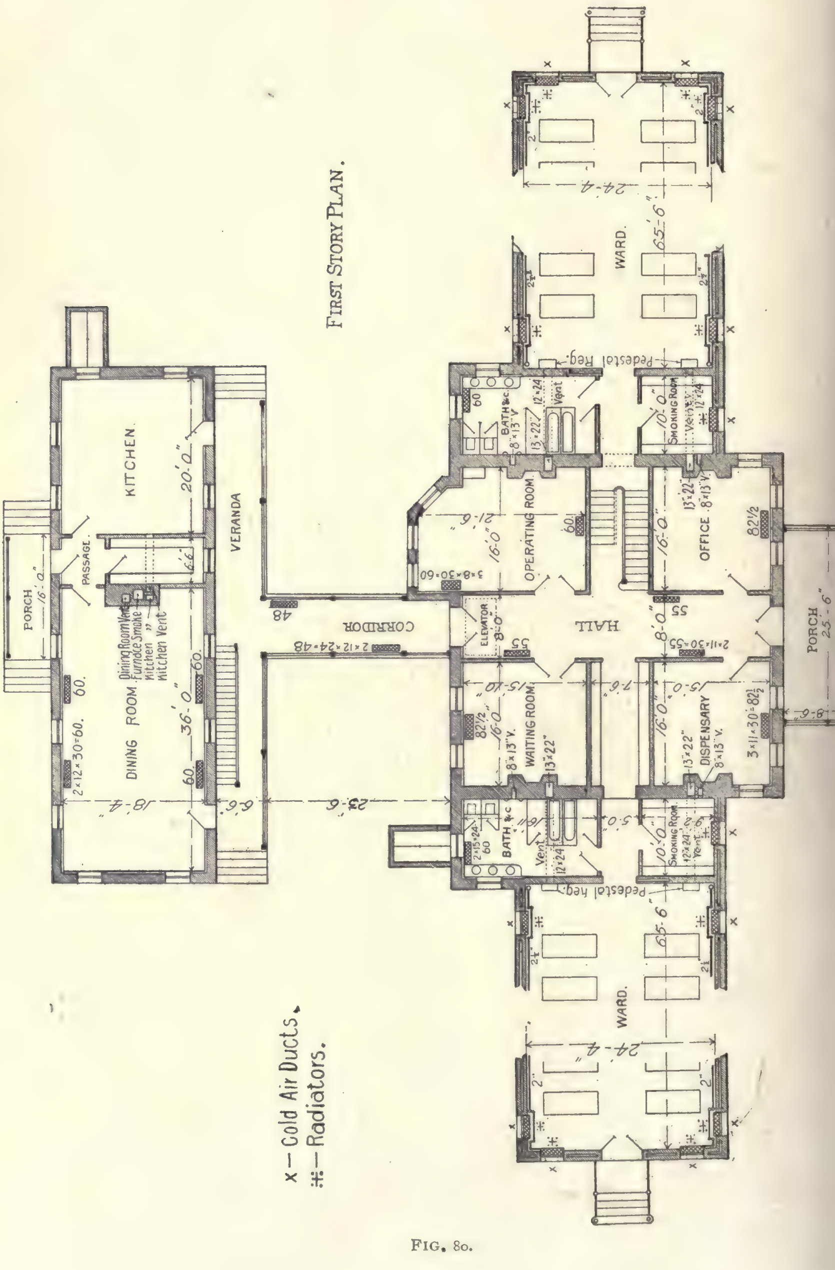

FIRST STORY PLAN.
x — Cold Air Ducts.
⁑ — Radiators.
KITCHEN
PASSAGE
PORCH
DINING ROOM
VERANDA
CORRIDOR
HALL
OPERATING ROOM
WAITING ROOM
OFFICE
DISPENSARY
ELEVATOR
BATH & C.
SMOKING ROOM
WARD
WARD
PORCH
Pedestal Reg.
Dining Room Vent
Furnace Smoke
Kitchen Vent

FIG. 80.

Figures 77 and 78 show the basement and floor plans of a small U. S. Army hospital, containing eight beds in the ward and heated by steam, with indirect radiation for the ward and direct radiators in other rooms.

The boiler for this plant is 6 feet long and 30 inches in diameter, with twenty-three $2\frac{1}{2}$-inch tubes. The indirect radiators are in galva-

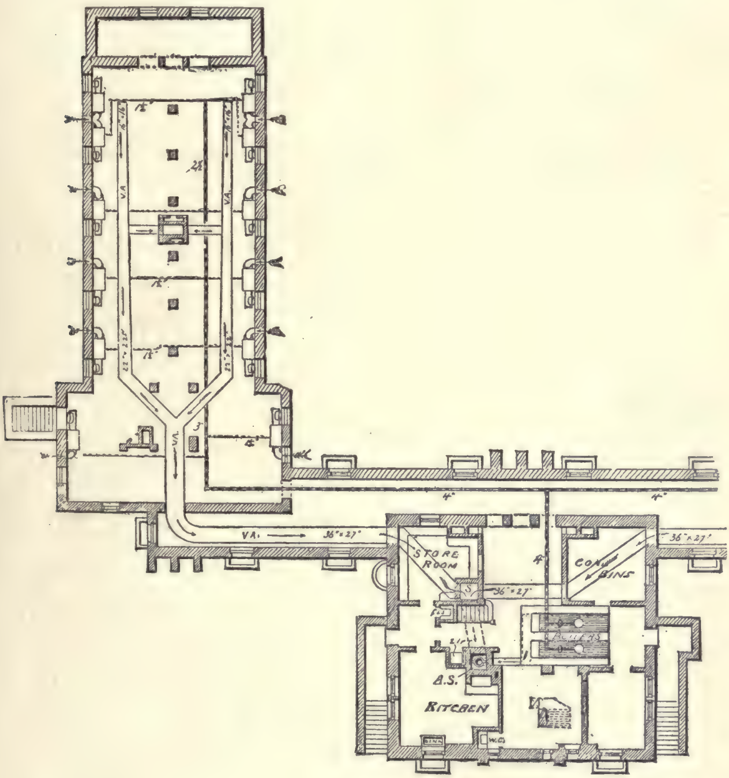


FIG. 81.

nized-iron chambers and are supported on iron bars. There are two outlet flues for the ward, leading to vertical shafts, as shown in Fig. 78. The amount of radiating surface is indicated for a temperature of 20° F.; it must be increased where the minimum temperature falls below this.

Figures 79 and 80 show basement and first-floor plans of a U. S. Army Post hospital of from 24 to 48 beds, depending upon the length of the wings, and intended for cold climates. The heating is by direct-indirect radiation in the wards, by direct radiation in other rooms. The location and dimensions of boiler and steam floor mains are given in Fig. 79.

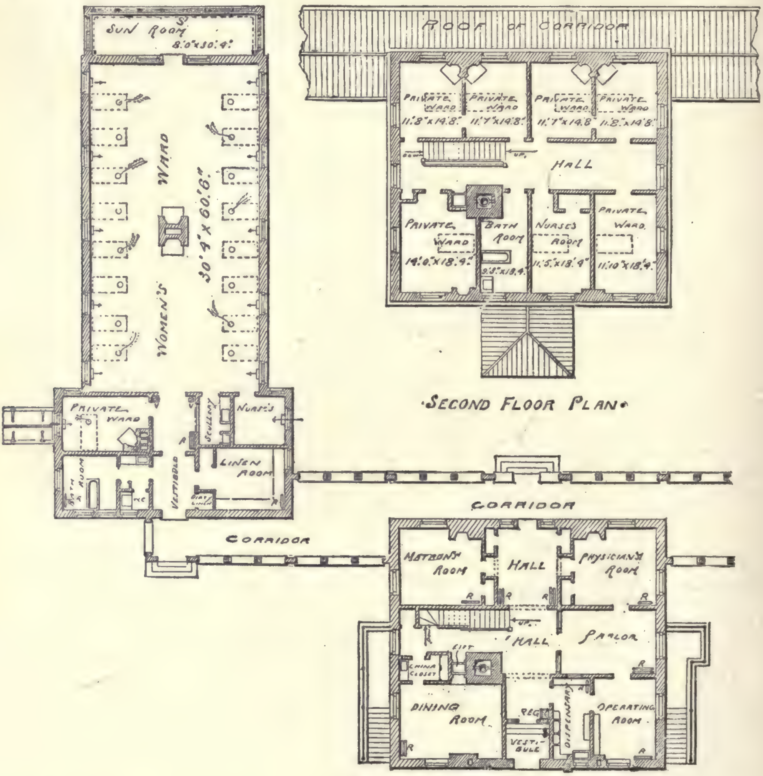


FIG. 82.

Figure 81 is a plan of a part of the basement, and Fig. 82 a plan of the corresponding portions of the first and second floors of the Cambridge Hospital, Cambridge, Mass.

The wards are connected with the administration building by roofed corridors. The sides of these are glazed, but in such a manner that the frames can be removed in fine weather. The upper stories of the administration building are to be used as private wards.

The main room of each pavilion is 30′ 4″ x 60′ 6″; the floor space to each bed being 115 square feet, and the cubical air space about 1,840 feet.

The sun-rooms at the ends of the pavilions are 8x30 feet, with hammered glass roofs and clear glazed sides extending almost to the floor. The level of the sun-room floor is very slightly below the floor of the principal ward, just enough to shed water outward, but not sufficient to interfere with the movements of an invalid's chair. The sun-room is on the south end of the wards, and the position of the pavilions being north and south, sunlight is available during the whole day.

The administration building is warmed by direct radiation, supplemented by indirect radiation in the main hall, and all sick rooms or chambers have an open fireplace. The pavilions are warmed by indirect radiation, supplemented by direct radiation in the sun-rooms, halls and bath-rooms.

The warming apparatus is arranged to be worked either as a low-pressure steam, or as a hot-water apparatus. Two boilers are used, located in the cellar of the administration building, 14 feet long by 42 inches in diameter, each containing 60 2½-inch tubes. These boilers are connected with a 21-inch vertical cast-iron smoke-pipe located within the aspirating shaft *A S*, cellar plan. Steam or hot water, as the case may be, is carried to the pavilions by the 4-inch pipes shown, where it is distributed to the indirect heaters, which are "pin" sections, center connection, eight sections being used to each hot-air box.

Figure 83 is a section and Fig. 84 a perspective elevation of one of these air boxes showing the arrangement of the air-inlet pipes *A*, mixing valve *D*, hot-air pipe *H*, and register box *R*, within the wards, as well as a section of the vent ducts *V A*, with the vent outlet under each bed (*V*).

The coil casings or air boxes are made of No. 22 galvanized iron, with flanged corners, and the steam radiator is suspended midway in the case. The cold air enters through the 10-inch round pipe *A*, Fig. 84, and shown separated on cellar plan by the arrows, the mouth of which is protected by a register face and frame. As the air enters through *A*, it can be made to pass either under and through or above the heating surfaces of the radiator by means of a sliding damper *D*, or the air current may be divided by placing the damper in a nearly central position, allowing some of the air to pass each way, thereby regulating its temperature without reducing its volume. The upper end of this damper is connected by a chain with a pull-and-stop mechanism within the ward, so that the attendant can regulate the heat

of the air without leaving the room. The registers are in every case underneath the windows between the piers.

The vent ducts shown on cellar plan are made of pine lined with zinc. They commence 16 inches square and increase to 22 inches

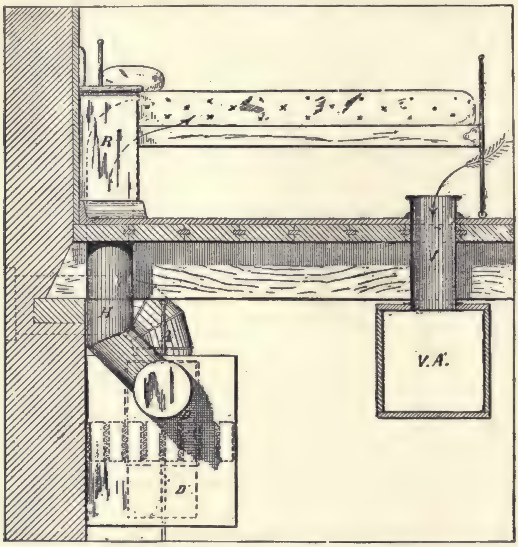


FIG. 83.

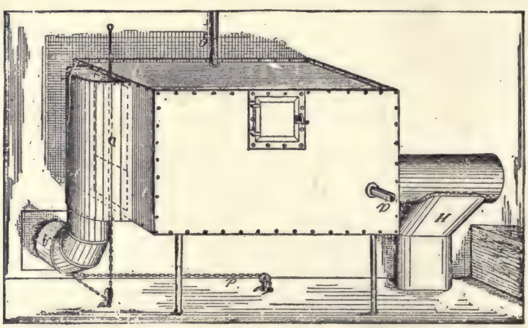


FIG. 84.

square for each side of each ward and then connect into a main duct 36x27 inches, their position being against the ceiling. At *S*, cellar plan, the main ducts from each pavilion enter a short down-shaft, that they may connect with the aspirating shaft below the floor to avoid

destroying the head room at the stairs. From the points marked *D D* on the ducts near the middle of wards, the vent duct (*V A*) is divided by a midriff in a horizontal plane. The object of this is to increase the certainty of all the vent openings under the beds drawing alike. At *D D*, also, are shown branch ducts entering stacks in the middle of the large wards. These stacks are to be used to exhaust the ducts in times when no heat is in the main aspirator or to be used as auxiliary to it.

Provision is made for a stove at the foot of each stack and fireplaces in the pavilion wards also open into it. The latter are intended for damp weather in summer, etc.

At *S S*, in the sun rooms, coils of pipe are run under the windows for extra warmth.

The ventilation of this hospital was designed by Dr. Morrill Wyman, and has proved very satisfactory. Dr. Wyman informs me that the heating is hardly sufficient in very cold weather, when hot water is used, the mains being too small, but steam has not been used for several years owing to the extra labor required in maintaining fires.

Figure 85 shows the basement plan of the Isabella McCosh Infirmary at Princeton, N. J., a small hospital for the benefit of sick students. Figures 86 and 87 are plans of the first and second floors.

The ventilation is by open fireplaces. The infirmary is heated by steam, and the number of feet of heating surface required in each room is marked on the radiator stacks shown on the basement plan. Each set of radiators receives its fresh-air supply directly from the outside air, and by means of a mixing valve operated from each room. The temperature of the incoming air is regulated to suit the requirements without diminishing its flow. Every heat flue has its separate set of radiators, fresh-air supply and mixing valve, and can be operated entirely independently of any other heat flue.

The basement plan shows by a light line parallel to the wall the surface of the inside finish, which is the same for the other stories, but is not indicated on the plans. The significance of the reference letters is as follows: *A* and *B*, radiator stacks, serving first and second stories, respectively; *C*, ash pit; *D*, living room; *E*, bedroom; *F* is a coal vault in the basement and a kitchen on the upper floors; *G*, coal vault; *H*, boiler-room; *I*, a double "Florida" boiler No. 66; *J*, pantry; *K*, cellar; *L*, dining-room; *M*, porch; *N*, ward; *O*, heat flue; *P*, private room; *Q*, linen room; *R*, steam pipe riser; *S*, nurses' room; *T*, hall; *U*, portable bath-tub; *V*, fixed bath-tub; *W*, light

well; *X*, direct radiator; *Y*, sun parlor; *Z*, operating room; *&*, apothecary's room.

Figure 88 is a vertical section through one of the first-floor radiator cases *A*. External cold air enters through the copper wire screen *C* over an aperture in the basement wall *W*, and when

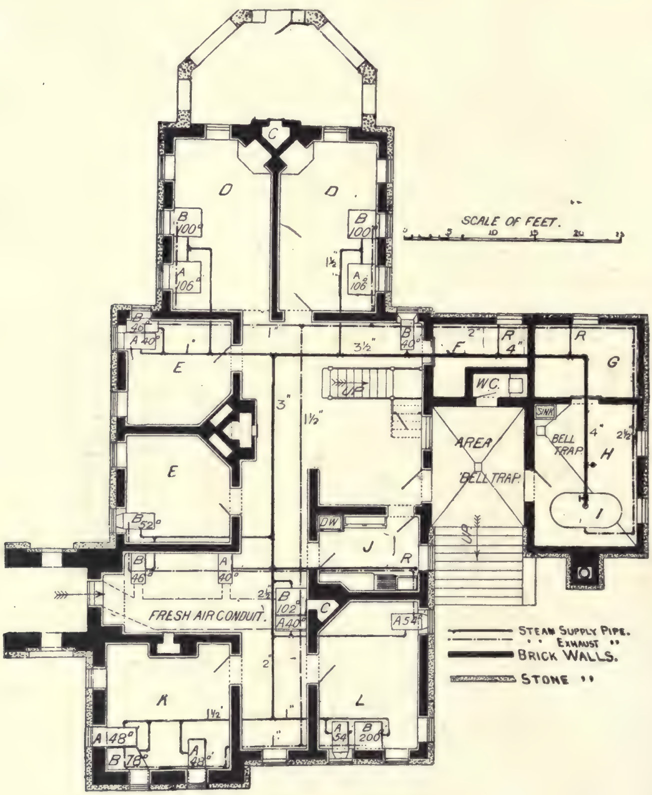


FIG. 85.

dampers are in a certain position, passes through cold-air chamber *E* and a perforated tin plate *G* to the radiator box *F*, which contains a Gold's pin radiator (not here shown), and thence rises to the hot chamber *H*, and is delivered through the flue *I* and the register *J*, to the first-floor room. *K* is a clean-out door, and *D* is a damper commander by the vertical axis and handle *L*, to regulate the amount of

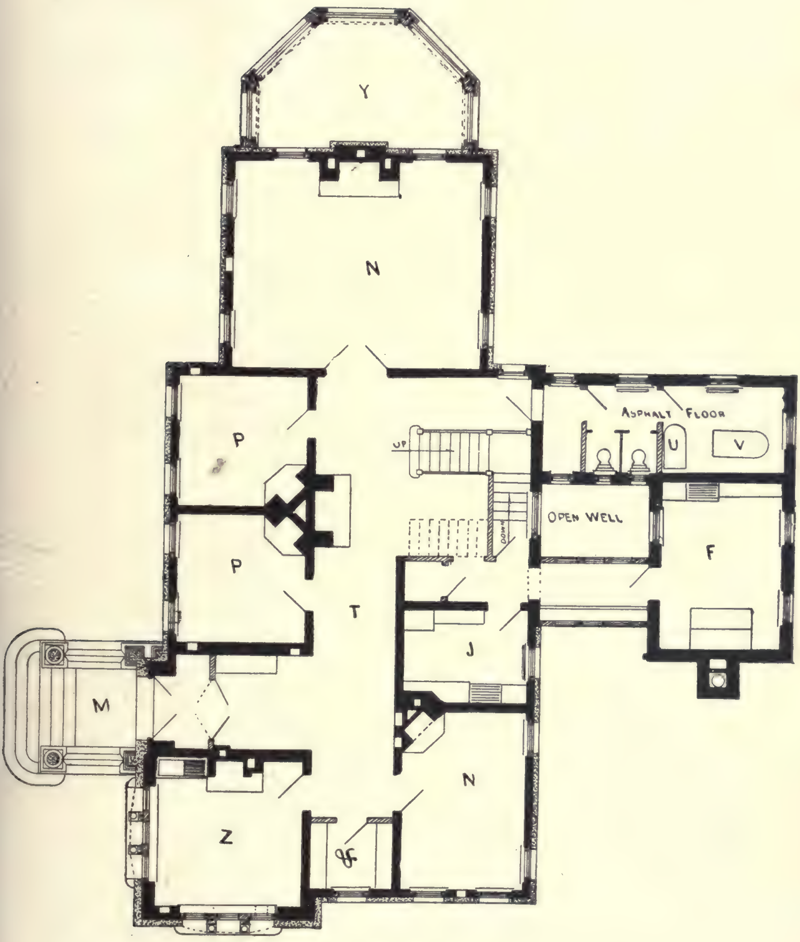


FIG. 86.

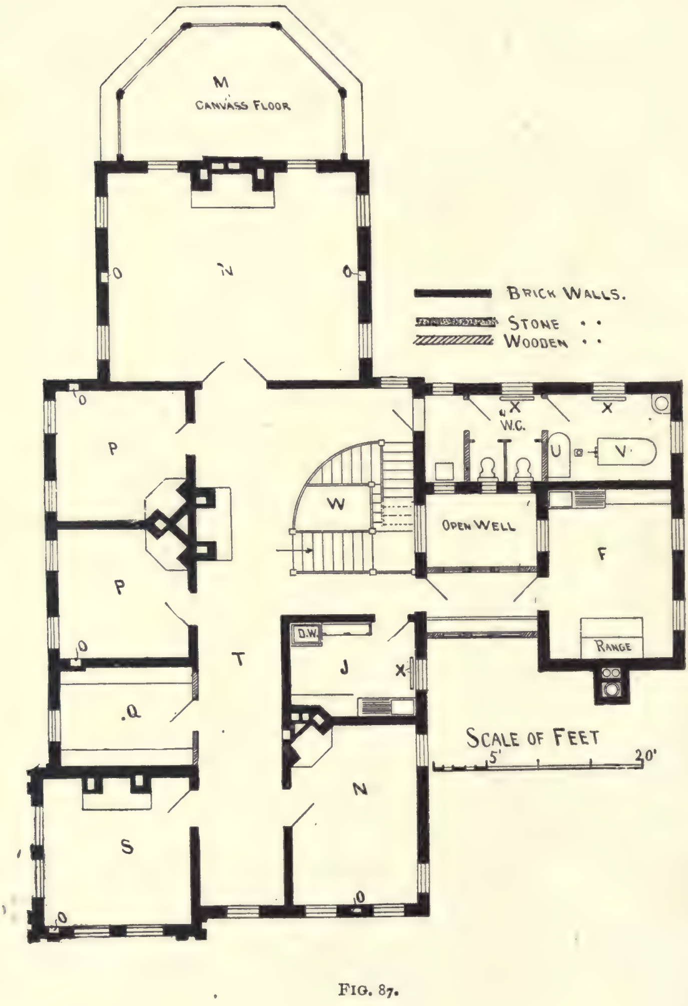

M
CANVASS FLOOR
N
BRICK WALLS.
STONE " "
WOODEN " "
X
W.C.
X
U
V
P
W
OPEN WELL
P
F
D.W.
T
J
X
RANGE
Q
SCALE OF FEET
5'
20'
N
S

FIG. 87.

cold air admitted. It is here shown wide open. The mixing valve *M* is here shown wide open for hot air. It is operated by the rod *N* and crank *P*, commanded by the lever handle *O*, which may be fixed at any position on its segment *Q* by a set screw. The valve *M* may be

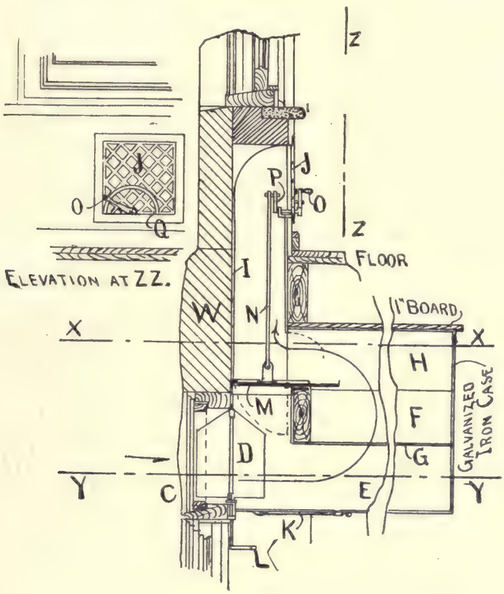


FIG. 88.

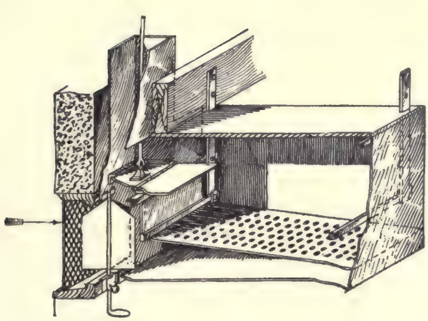


FIG. 89.

revolved about its horizontal axis, as indicated by the dotted lines, so as to admit all cold air direct from the inlet *C*, or any desired proportion of hot and cold air, always admitting the same total volume of fresh air, whatever its position.

Figure 89 is a sectional perspective of the radiator case. Figure 90 is a plan at *Y Y*, and Fig. 91 is a plan at *X X*. In Figs. 90 and 91 parts of two radiator cases are shown, each symmetrical about its center line. They differ only in that *S* is 26 inches wide made to clear window *R*, and *T* is a wider one, obscuring the window.*

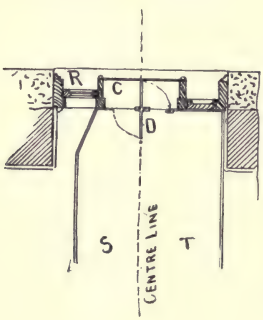


FIG. 90.

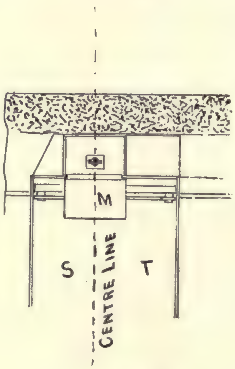


FIG. 91.

Figure 92 is a plan of the basement of the Miners' Hospital at Hazleton, Pa. The fresh air is furnished by a propelling fan 4 feet 6 inches in diameter located at *F*, which forces it through a radiator chamber and thence through the outlined ducts. The ducts indicated in solid black are for foul air, and lead to an exhaust fan, also 4 feet 6 inches in diameter, located at *F'*, where it discharges into a chimney. Figure 93 is a plan of the main floor showing the position of the foul-air outlets in the floor of the wards. The system is intended to change the air in the wards four times an hour. The building contains 159,927 cubic feet, and the heat and power are furnished by two connected 30 horse-power horizontal tubular boilers.†

Of all small hospitals in this country with which I am acquainted, the one in which the heating and ventilation has been most thoroughly proved to be satisfactory is the Barnes Hospital, at the Old Soldiers'

* From *The Engineering Record*, June 11, 1892.

† From *The Engineering Record*, January 18, 1890.

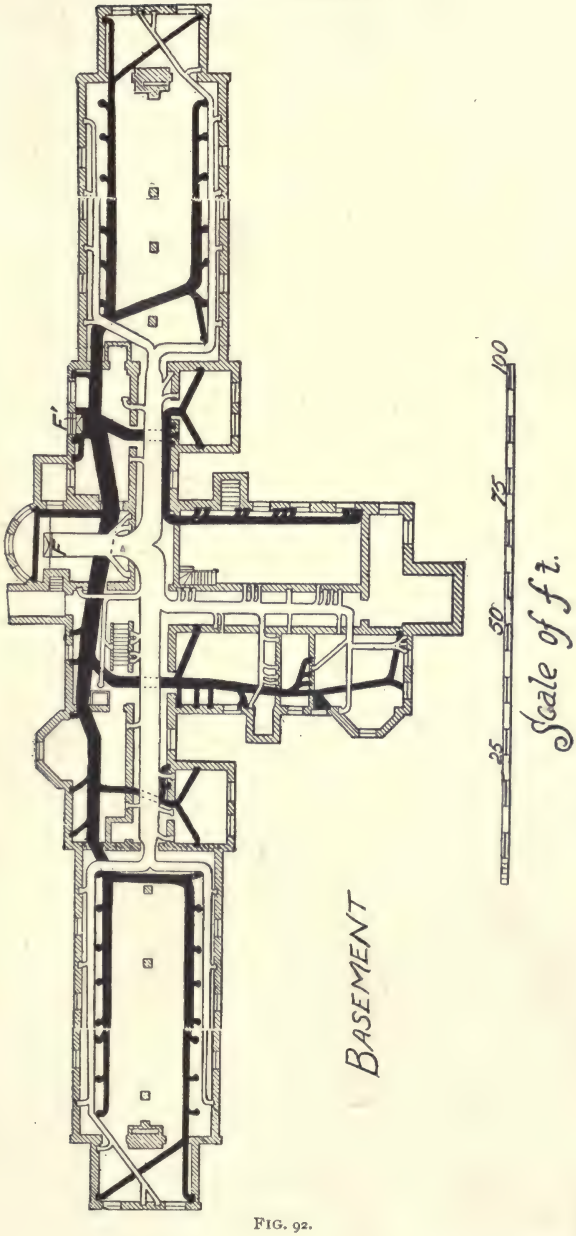


FIG. 92.

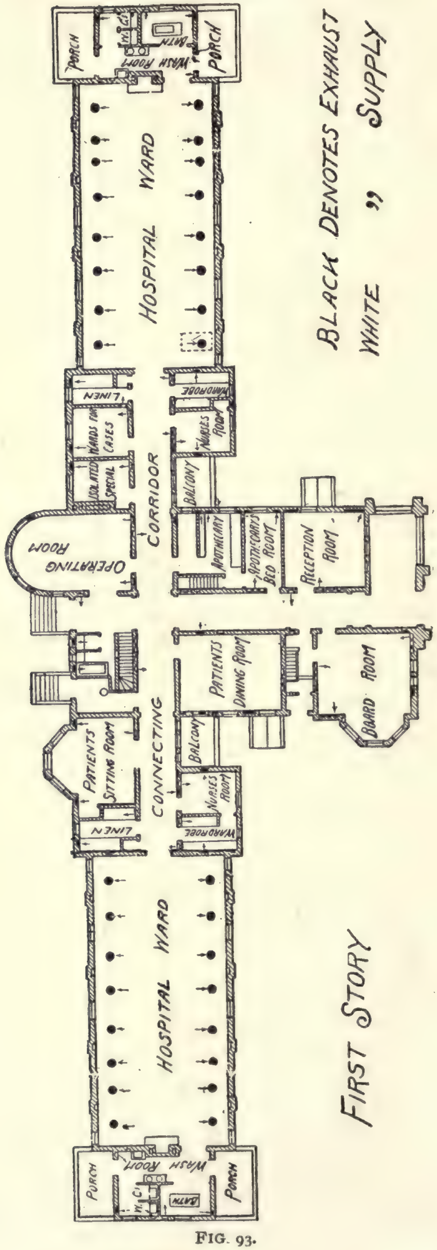

BLACK DENOTES EXHAUST
WHITE " SUPPLY
FIRST STORY
PORCH
WASH ROOM
BATH
W. C.
HOSPITAL WARD
LINEN
WARDROBE
NURSES ROOM
WARDS FOR SPECIAL CASES
ISOLATED
BALCONY
CORRIDOR
OPERATING ROOM
APOTHECARY
APOTHECARY'S BED ROOM
RECEPTION ROOM
PATIENTS DINING ROOM
BOARD ROOM
PATIENTS SITTING ROOM
CONNECTING

FIG. 93.

Home, near Washington, the general arrangement of which is shown in Figs. 94 and 95.

This hospital is built of brick, and consists of a central administration building measuring 52x55 feet, two pavilion wings each 64x29 feet, and two end towers each 24x46 feet. The central building has a basement, three stories and a mansard roof, the rest of the structure two stories, with basement and mansard.

The total amount of cubic space to be heated is about 310,000 cubic feet. The basement is occupied by the heating apparatus, which is hot water, and consists of two tubular boilers, each 9 feet long and 42 inches in diameter, with mains, pipes and coils. The heating coils are of cast-iron pipe, 3 inches in diameter, and are placed in fresh-air

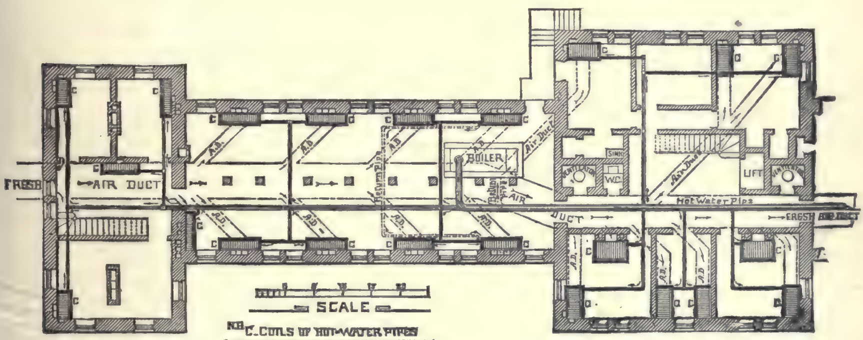


FIG. 94.—BARNES HOSPITAL, PLAN OF BASEMENT, WITH FRESH-AIR DUCTS AND HEATING APPARATUS.

chambers in the basement, as shown in the plan. At the point of entrance of the supply pipe to each coil is a valve, by which the flow of hot water may be diminished to any degree, and the temperature of the coil regulated accordingly.

The fresh-air flues are of terra-cotta pipe, built into the walls and opening into the space above the heating coils.

The apparatus has maintained a uniform temperature of about 70° F. in the coldest weather, and the temperature can be varied at the different registers to suit the feelings of patients near them.

When the natural ventilation by open windows is insufficient or impracticable, fresh air is supplied by a shaft 8 feet in diameter and 38 feet high, placed 74 feet west of the building. This shaft is con-

nected with a brick air duct, 286 feet long, which passes beneath the basement through its entire length, and gives off branches leading to the air chambers containing the heating coils.

At the point of junction of the vertical shaft with the fresh-air duct is located the fan, which is 8 feet in diameter and has 24 blades, each 12 inches wide.

The motive power for this fan is furnished by a six horse-power engine, and the amount of coal required to run it is about 140 pounds for 24 hours. The fan is usually run at 60 revolutions per minute, giving a velocity in the air duct of from 400 to 600 feet per minute, the cross-section of the duct at its throat being 40 feet square. The removal of foul air by aspiration is affected by two chimneys in the administration building. Each chimney measures 4′4″x5′8″, and is 96 feet high.

A boiler-iron flue, 2 feet in diameter, is placed in the center of each chimney, extending from the basement to a height of 3 feet above the chimney cap ; into these flues pass all the products of combustion from the hot-water and steam-boiler furnaces, as well as those from the kitchen range. Each flue has a basket grate at its base, in which a fire can be built when the furnaces are not acting.

Into the chimney shafts outside these flues empty the foul-air ducts from the wards. These ducts are 3 feet 3 inches wide, 1 foot deep and 50 feet long, and are placed above and below the center of each ward with which they communicate by accurately closing registers placed in the center of the floor and ceiling. These foul-air boxes are lined with tin and are cleaned daily.

Each ward contains 12 beds, is 50′ x 24′ x 15′, and has five foul-air registers along the center line of the floor, and five in the ceiling.

Each of the upper registers has a clear area of 1.33 square feet of opening, and each lower register 1.5 square feet of clear opening. Each lower ward has 16 fresh-air inlets, eight being 10 inches above the floor and eight 10 inches below the ceiling; in the upper wards the upper registers are omitted. Each fresh-air register has a clear area of 1 square foot.

The double set of inlets in the lower wards was arranged for experimental purposes to test the value of General Morin's theory that the warm air should be introduced at the ceiling. It was found that when this was done there was a difference of 10 degrees in the temperature between the floor and the ceiling, and that the patients complained of cold feet and discomfort. It is also evident that when the warm air is introduced near the ceiling it is impossible to vary the tem-

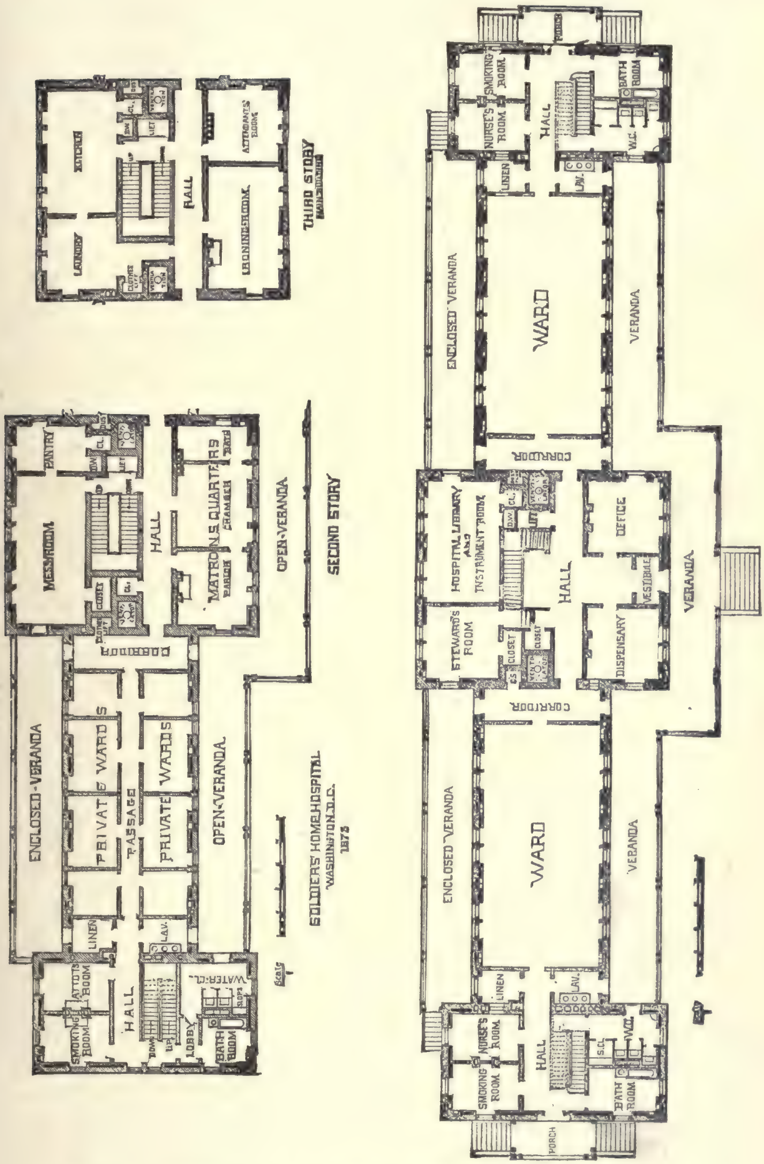


Fig. 95.—HOSPITAL AT SOLDIERS' HOME, WASHINGTON, D. C.

perature at different beds, a thing which it is often desirable to accomplish in a hospital.

The mean velocity of the upward current of air in the aspirating chimneys is about 180 feet per minute. With good fires in the grates at the base of the flues the highest recorded velocity was 700 feet per minute.

Each chimney under ordinary circumstances removes from the two wards connected with it about 36 cubic feet of air per second, or 1½ cubic feet per second per man.

This supply can be at any time doubled by the use of the fan. When fires are used at the base of the chimneys to accelerate the aspiration the consumption of coal is about 30 pounds of anthracite per hour per grate.

The following data are taken from a report which was printed for the use of trustees of the Johns Hopkins Hospital, in Baltimore, but which was never published, and is now rare. The observations were made and reported by Surgeon D. L. Huntington, U. S. Army, to whose superintendence much of the success of the system was due.

The following are instances of experimental use of the fan :

June 7. External air 75° F.: 5 P. M., temperature of air-supply duct 68° F., 20 pounds steam; 120 revolutions of fan per minute.

Velocity of air at throat of duct (40 square feet area) 1,350 feet per minute at the nearest inlet into ward :

1st story (100 feet from throat)	450	feet per minute.
2d " 118 " "	420	" "
3d " 132 " "	340	" "

At most remote inlet into ward :

1st story (298 feet from throat)	410	feet per minute.
2d " 315 " "	220	" "
3d " 331 " "	139	" "

On this trial all registers were open, also all doors, windows, and ventilating outlets, the resistance to the fan being reduced to a minimum.

Nov. 1. Temperature of external air 45° F., of duct 46° F., 20 pounds steam ; 120 revolutions of fan per minute.

Velocity of air at throat of duct 1,320 feet per minute at the nearest inlet to ward:

1st story (same distance as above)	530	feet per minute.
2d " " " "	360	" "
3d " " " "	269	" "

At most remote inlet into ward:

1st story	750	feet per minute.
2d "	500	" "
3d "	298	" "

In this experiment all windows and doors were closed, the ventilating registers and outlets being open.

It will be seen that in the first experiment the pressure of the air as indicated by the velocity was greatest at the inlets nearest the fan, while the reverse was the case in the last trial. The direction and force of the prevailing wind also has a very considerable influence on the movement of air through the fan and in the duct. Dr. Huntington remarks that "a long series of experiments at different seasons of the year have all yielded harmonious results. Beyond a velocity of from 800 to 900 feet per minute in the main duct, the effective force of the air is much impaired, and the result usually seen at the inlets nearest the fan is a lessened current. The general rule in working the fan is to use 15 pounds of steam and not over 60 revolutions per minute, equal to from 400 to 600 feet per minute in the duct; this gives all the air needed for the building, and brings the consumption of fuel to its lowest point. With this velocity air enters the wards at the rate of from 2 to 4 feet per second."

A specially interesting experiment was made in one of the wards on the night of November 28, which is thus reported by Dr. W. M. Mew, who made the air analyses. Ward B (for 12 beds) contained 11 patients; the ordinary ventilation was going on.

Ward D had 12 beds; all occupied. All the outlets had been closed for 35 minutes before the first experiment, in order to make the air thoroughly impure, which was accomplished, as is shown by the high percentage of carbonic acid obtained.

The second experiment was made in the same ward just 10 minutes later, during which time the outlet and inlet flues were open and the fan making 60 revolutions per minute.

It will be seen from the following table that the use of the fan in this way for 10 minutes made the very impure air of the ward nearly as pure as the outer air:

Air, Whence Taken.	Temperature.		Difference.	Relative Humidity.	Vols. of CO_2 in 10,000.
	Dry Bulb.	Wet Bulb.			
Outside	49° F.	45° F.	4	73	3.05
Ward B	68° F.	57° F.	11	40	6.35
Ward D, 1st experiment	77° F.	61° F.	16	38	11.23
Ward D, 2d "	80° F.	66° F.	14	..	3.75

At the time of this observation there was very little wind, the barometer was 29.72, the temperature in the aspirating chimneys was 79° F., and the average velocity of the upward current in them was 120 feet per minute.

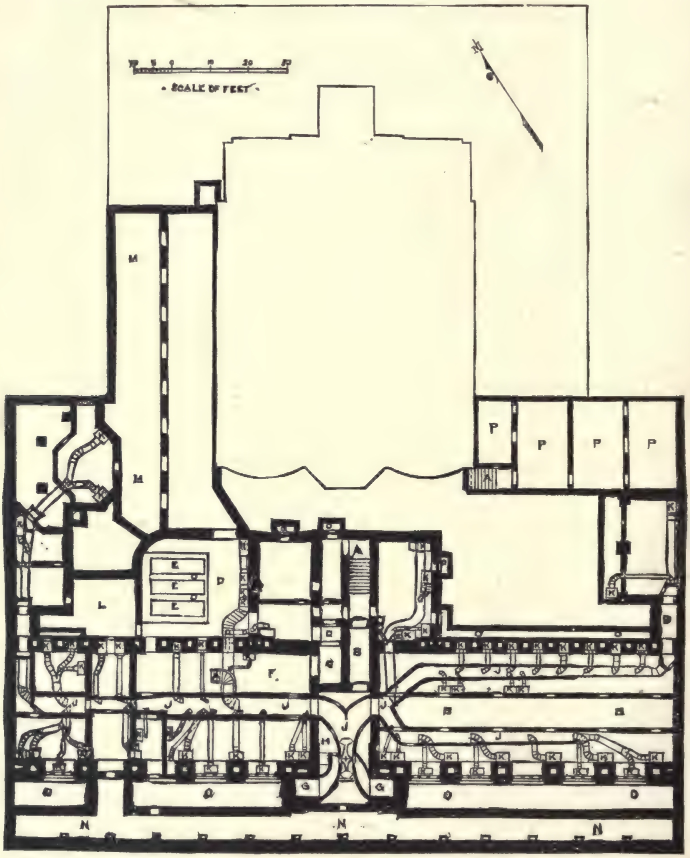


FIG. 96.—NEW YORK HOSPITAL BUILDINGS.—PLAN OF CELLAR.

A.—Stairs.
B.—Corridor.
C.—Elevator.
D.—Boiler room.
E.—Boiler.
F.—Engine room.
G.—Fresh-air duct.
H.—Engine.
I.—Fan blower.
J.—Cold-air duct.
K.—Steam coils.
L.—Ash vaults.
M.—Coal vaults.
N.—Vaults.
O.—Area.
P.—Vegetable vaults, etc.
Q.—Ice house.

The placing of the kitchen in the third story of the hospital has been a decided success in more ways than one. The odors from cooking are almost entirely excluded from the building, although sometimes

the lift which passes from the kitchen to the dining room acts as a sort of air-pump, and draws or forces some of the air from the kitchen down to the second floor.

This principle of placing the kitchen on the upper floor was adopted in the New York Hospital, the plans for which, prepared by the architect, Mr. George B. Post, were adopted in 1875.

This hospital is located near the center of New York City, and is an illustration of an attempt to make up in height for deficiency in ground area.

The general arrangement is shown in the accompanying plans, which are copied from those prepared by the architect to illustrate his description of the building, which is of brick, and contains 163 beds. In the wards there is one window to each bed, each external pier of the building being a flue, which is lined with hollow bricks to prevent, as far as possible, loss of heat by radiation. Through the center of these flues run cast-iron pipes, intended to be fitted so as to be air-tight, and through which fresh air is taken to the building, being forced in by a fan.

The spaces outside these fresh-air pipes are the foul-air flues. These terminate above in pipes leading to an exhaust fan, which is located in the top of the center building.

The heating is by steam, the coils being arranged at the bottom of the fresh-air pipes in such a way that by a valve the cool air from the propelling fan can be sent either through or around the heating coil. The fresh air is admitted to the wards through slits in the window sills, forming a jet directed upward on the principle of Tobin's tubes. A similar arrangement exists in the pavilion of the London Hospital, erected in 1875–6.

The openings for the exit of foul air from the wards are in part placed in the walls of the piers and in part beneath the beds.

No effort or cost was spared in the construction of this building to overcome the difficulties connected with the arrangement of heating and ventilation of a building of so many stories, all of which through the staircase halls and elevator shafts are practically in free communication with each other, and a fair amount of success has been attained. I do not know of any published observations showing what the actual operation of the apparatus is, but I have visited the hospital several times, and have twice tested the currents with an anemometer. These testings made the average air supply to be about 2,400 cubic feet per bed per hour—an insufficient amount, if all the beds were full, which, however, was not the case.

The principle of placing fresh-air pipes inside of the foul-air ducts is one that cannot be approved of for hospital ventilation, for although the fresh-air pipes are of iron, and may have been tightly fitted, it is a

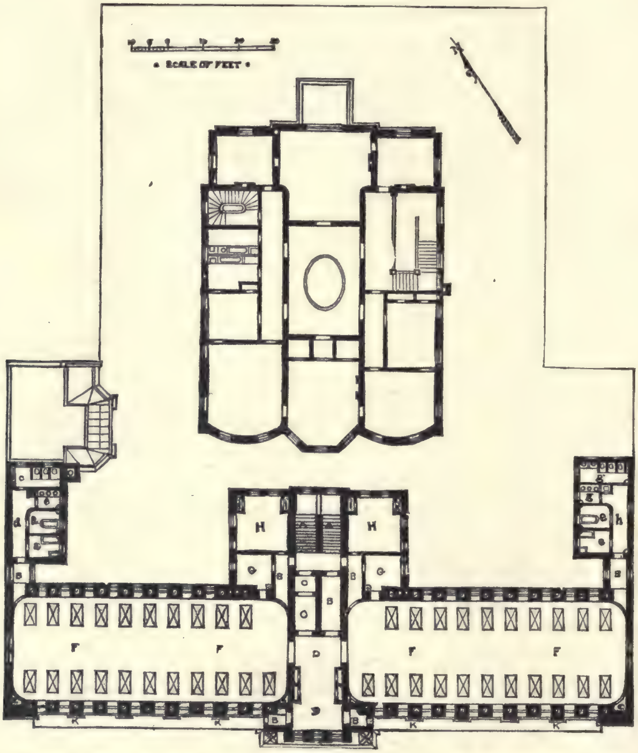


FIG. 97.—NEW YORK HOSPITAL BUILDINGS.—PLAN OF SECOND, THIRD AND FOURTH STORIES.

MAIN BUILDING.

A.—Stairs.
B.—Corridor.
C.—Elevator.
D.—Hall.
E.—Closet.
F.—Ward.
G.—Nurses' room.
H.—Dining room.
I.—Dumb waiter.
J.—Ventilating duct.
K.—Balcony.

WEST WING.

a.—Bath-room.
b.—Sink.
c.—Toilet room.
d.—Corridor.

EAST WING.

e.—Bath-room.
f.—Sink.
g.—Toilet room.
h.—Corridor.

ADMINISTRATION BUILDING.
Library and Museum Floor.

mere question of time when some communication will be established between the inner and outer surfaces of these pipes, either by rusting or by alternate expansions and contractions, and then the foul air may

be carried back into the wards. The iron pipes are not readily accessible, being enclosed in the walls, and there is no ready means of determining their condition.

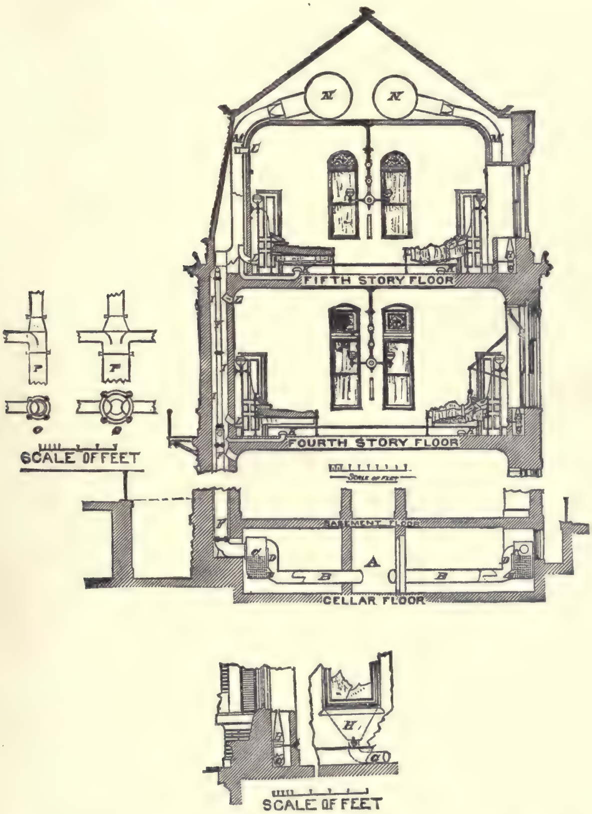


FIG. 98.—NEW YORK HOSPITAL BUILDINGS.—DIAGRAM OF VENTILATION AND HEATING.

A.—Main fresh-air shaft from blower.
B.—Connection to steam coil.
C.—Steam coil.
D.—Cold-air passage around steam coil.
E.—Valve to regulate temperature by passing any required portion of the air around the steam coils.
F.—Hot-air pipes.
G.—Connections to registers.
H.—Register box and opening.
I.—Ventilating flue containing hot-air pipes.
K.—Main orifices for ventilation.
L.—Orifices for ventilation for occasional use.
M.—Ventilating pipes.
N.—Trunk ventilating pipes leading to exhaust blower.
O.—Plans of connections of hot-air pipes.
P.—Sections through connections of hot-air pipes.

One of the most satisfactory of existing hospitals as regards its heating and ventilation is the Johns Hopkins Hospital, in Baltimore, the block plan of which is shown in Fig. 99.

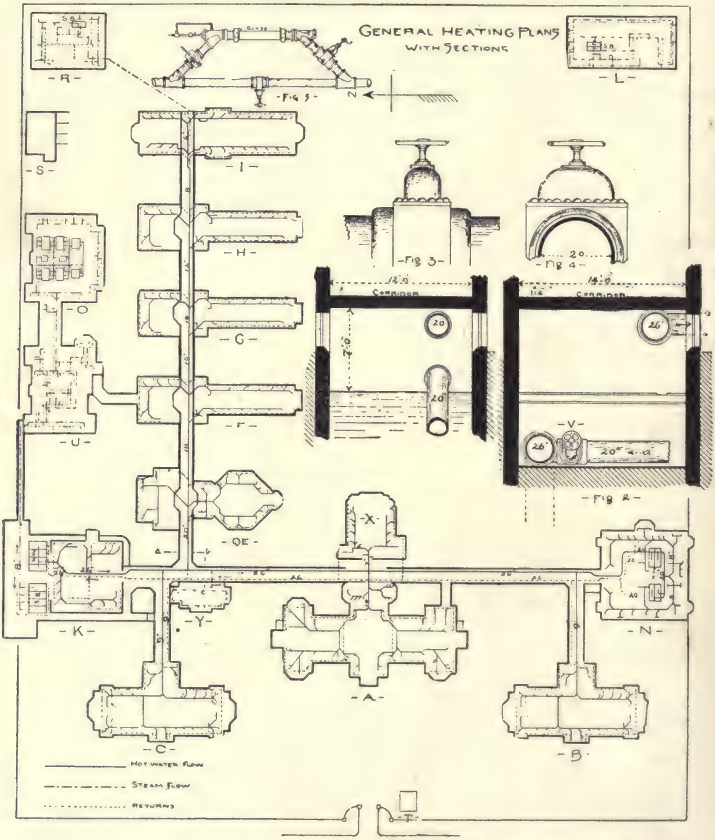


FIG. 99.—BLOCK PLAN OF JOHNS HOPKINS HOSPITAL.

A.—Administration building.
B C.—Pay wards.
D E.—Two-story octagon ward.
F G H.—Common wards.
I.—Isolation ward.
K.—Kitchen.
L.—Laundry.
N.—Nurses' home.
O.—Dispensary.
R.—Mortuary.
S.—Stable
T.—Janitor's lodge.
U.—Amphitheater.
X.—Apothecaries' building.
Y.—Baths.
Fig. 2.—Cross-section of corridor and pipe tunnel beneath.
Figs. 3-4.—Cut-off valve on hot-water main.

In this hospital the heating of all the wards and of the administration and apothecaries' buildings, the nurses' home and the kitchen is effected by hot water, the heat being furnished by four boilers in the vaults of the kitchen building and two in the cellar of the nurses'

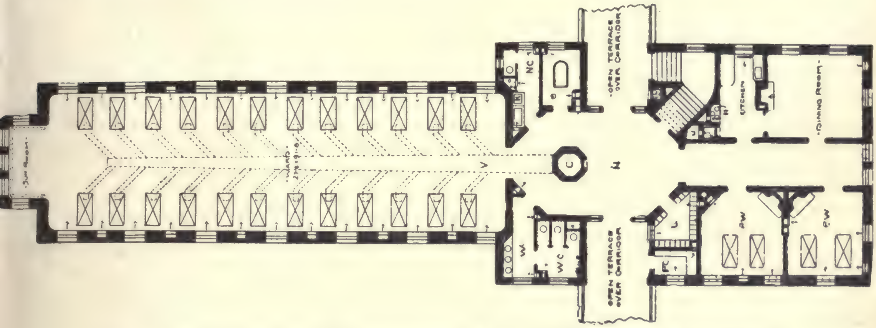


FIG. 100.—FLOOR PLAN OF COMMON WARD, JOHNS HOPKINS HOSPITAL.

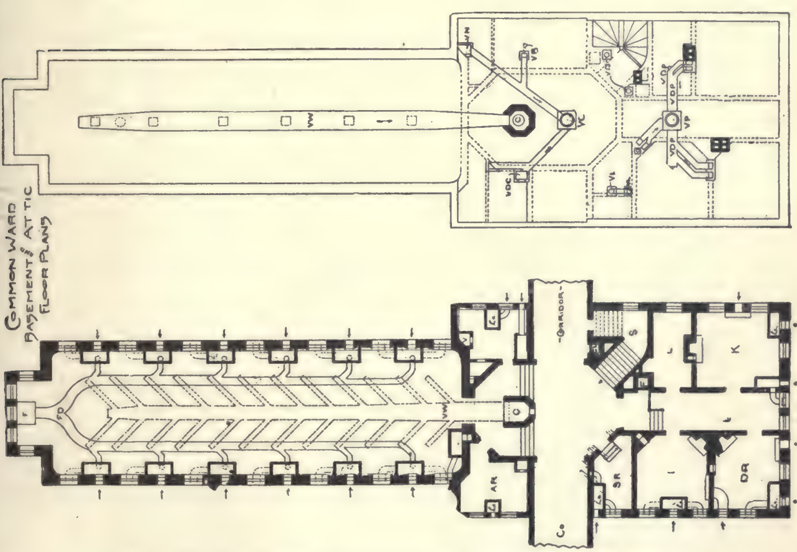


FIG. 101.—BASEMENT AND ATTIC PLANS OF COMMON WARD.

home, each boiler being 16 feet long, 5 feet in diameter and containing 106 3½-inch tubes. The outflow main is 26 inches in inside diameter and the entire system contains about 175,000 gallons of water.

The heating of the amphitheater and dispensary is effected by low-pressure steam from boilers at the kitchen building. Figure 100 shows the main floor plan, Fig. 101 the basement and attic plans, Fig. 102 a longitudinal section, and Fig. 103 a cross-section of one of the common wards.

The common wards are each contained in a separate pavilion of one story with a basement. The basement is devoted entirely to heating and ventilation purposes, forming practically a large, clean air chamber containing the hot-water coils for heating, and from which the air supply for these coils can be taken when desired. Usually, however, the supply is taken directly from the external air. Each of these

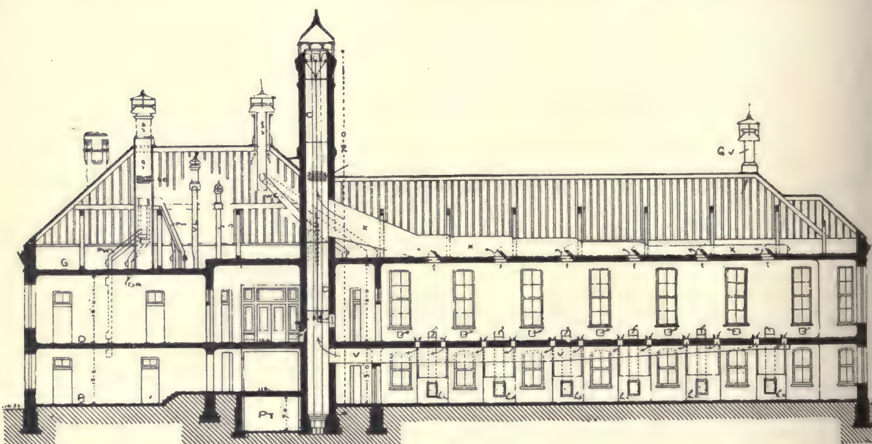


FIG. 102.—LONGITUDINAL SECTION OF COMMON WARD.

wards is practically a separate small hospital, and it is impossible to pass from one ward to another, or from the corridor which connects the basements to the wards, without going into the open air.

Each of the wards has a separate aspirating chimney, located as shown in the plans, in an octagonal hall or vestibule on the connecting corridor. Into this chimney empties a foul-air duct, which runs longitudinally beneath the center of the floor of the ward, and which receives the air from lateral ducts opening beneath the foot of each bed. The main foul-air duct is made of wood, lined with galvanized iron, and the lateral pipes are of galvanized iron, and cylindrical in shape.

A similar duct is placed above the ceiling and communicates with the ward by five openings in the ceiling, in the longitudinal central

axis. Just above where this upper duct enters the chimney, there is placed in the shaft a coil to be heated by high-pressure steam when it is necessary to quicken the aspirating movement.

It will be seen, therefore, that the foul air can be taken either at the level of the floor beneath the beds or from the center of the ceiling; the first method being employed in winter and the second in summer.

FIG. 103.—CROSS-SECTION OF COMMON WARD.
V.—Lower foul-air duct. *X.*—Upper foul-air duct.

The main central aspirating chimney is devoted to the ventilation of the ward only. All the service rooms have separate and independent exit shafts of galvanized iron passing up through the roof, and capped with a modification of the Emerson ventilator.

One of the common wards has a small propelling fan placed in the basement, the ducts from which open beneath the heating coils, the object being to secure a thorough air flush of the ward two or three times a day, and also to supplement the aspirating shaft on the very

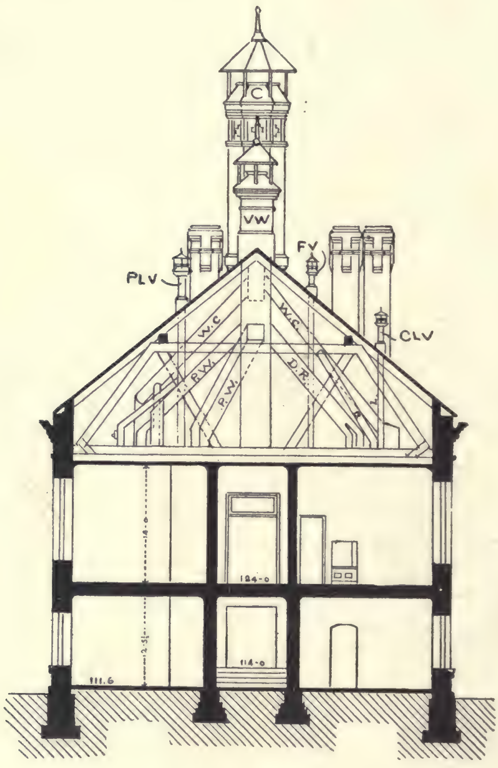


FIG. 104.

C.—Central ventilating chimney.
V W.—Water-closet vent shaft, 24 inches in diameter.
W C.—Closet vent shafts.
P W.—Vent flues for private wards.
D R.—Dining-room vent flue.
C L V.—Soiled clothes-lift vent.
F V.—Food-lift vent.
P L V.—Patients' clothing and clean linen vent shaft.

few days of the year when such aid may be useful, but it has been found that the aspirating chimney is sufficient to do all that is required, and hence such fans have not been placed in the other wards.

Figure 104 is a transverse section of service building of common ward through kitchen, showing foul-air ducts.

In the two-story Octagon Ward the foul-air aspirating chimney is placed in the center of the ward as shown in the section of this building given in Fig. 105.

This chimney is 8 feet in diameter internally, and has on each face two openings from the ward—one near the floor, the other near the ceiling—each being 20x26 inches.

Within this chimney is set a tube of boiler iron, 5 feet 9 inches in diameter, resting on a projecting cast-iron base, and extending from the ceiling of the lower ward to above the ceiling of the upper one.

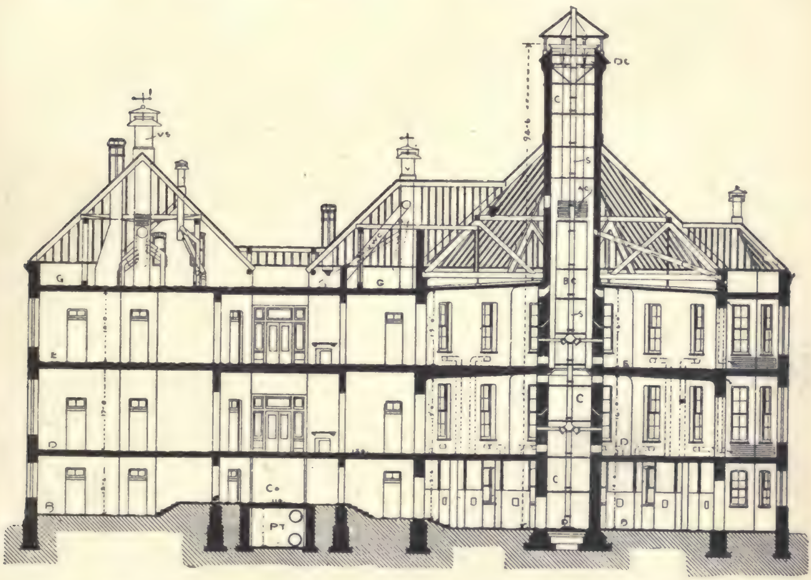


FIG. 105—LONGITUDINAL SECTION OF THE OCTAGON WARD.

Into the space between this iron tube and the brick wall of the chimney the openings from the upper ward enter, and just above the top of the iron flue is the accelerating steam coil. In these wards the general direction of the air currents is from the circumference toward the central shaft.

Figure 106 is a transverse section through the water closets of this ward, showing foul-air flues.

Figure 107 shows main floor plan and transverse section of one of the pay wards, Fig. 108 a longitudinal section, and Fig. 109 a trans-

verse section, showing together the arrangement of fresh-air and foul-air ducts.

The results of the above-described heating and ventilating apparatus have been very satisfactory. In the wards the proportion of carbonic impurity due to respiration has been found to be about 2 parts in 10,000.

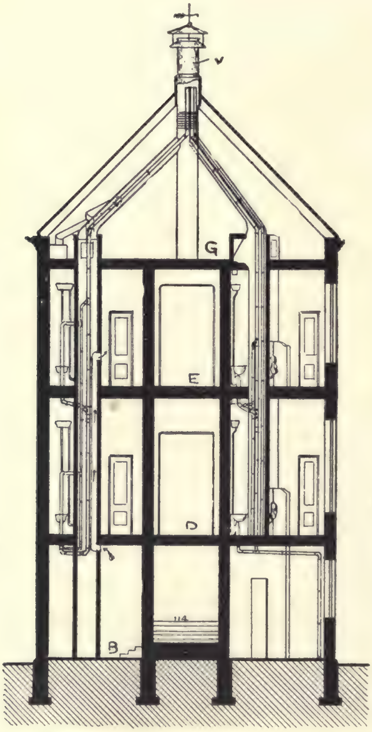


FIG. 106.

The largest and most costly hospital recently constructed is probably the new City Hospital near Hamburg, opened in 1890, and containing about 1,300 beds. The basement and main floor plans of one of the one-story common wards are shown in Figs. 110 and 111, the longitudinal section in Fig. 112, and transverse sections in Figs. 113 and 114.

In these wards the heating is effected by heating the entire floor on the principle of the ancient Roman hypocaustum. Beneath the floor, as shown in the sections, are flues about 30 inches square, internal measurement, constructed of brick and concrete, and covered by

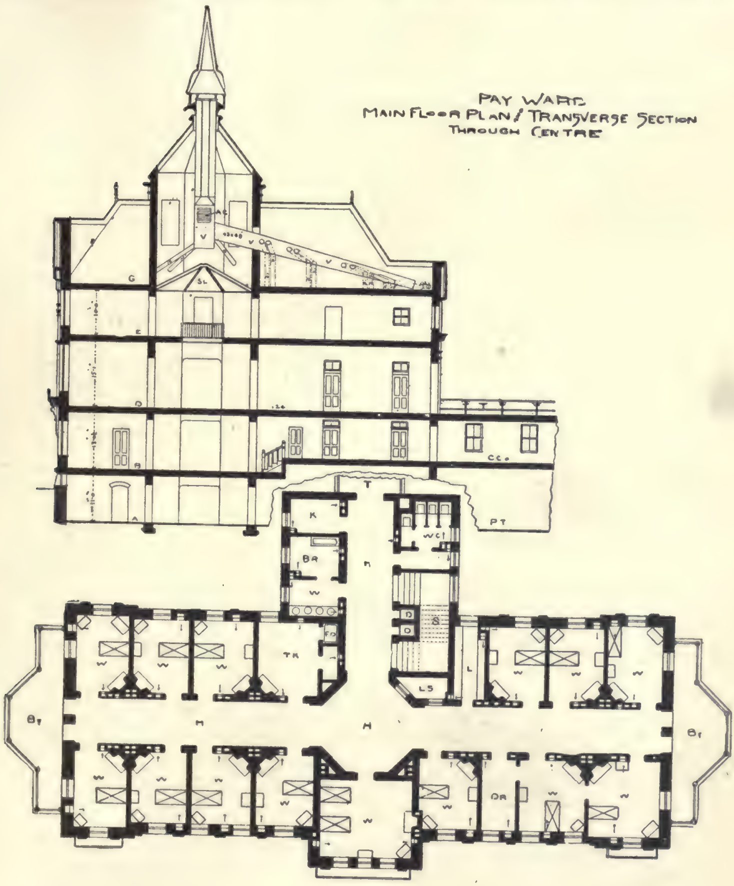


FIG. 107.

cement and marble tiles forming the ward floor. In these flues are placed the steam-heating pipes. The air admitted through the fresh-air inlets can be warmed by the radiators, *H*, shown in the figures. The foul air escapes by openings at the ridge.

FIG. 108.

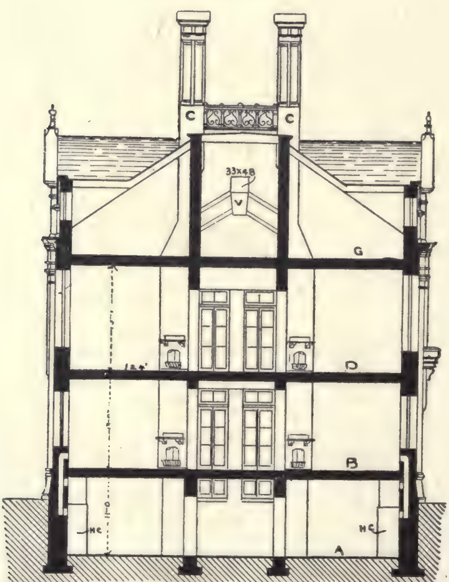


FIG. 109.

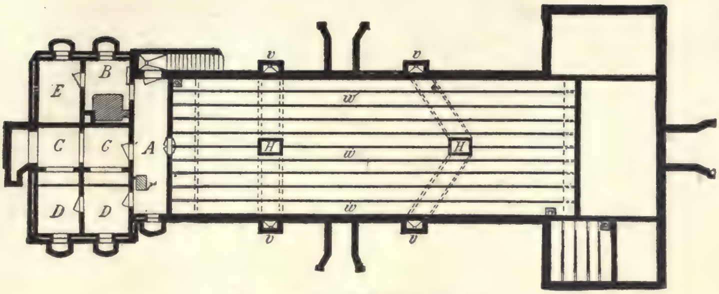


FIG. 110.—BASEMENT PLAN.

A.—Transverse corridor.
B.—Boiler room.
C.—Coal vaults.
D.—Store-rooms for utensils.
E.—Stoker's room.
H.—Radiators.
r.—Soiled-clothes chute.
v.—Air ducts.
w.—Separating walls in hot-air flues under floor.

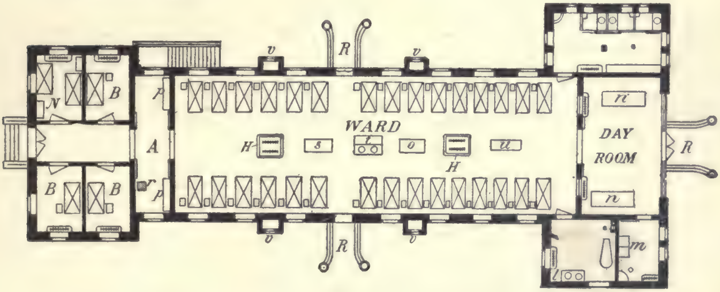


FIG. 111.

A.—Transverse corridor.
B.—Isolating rooms.
H.—Radiators.
N.—Attendant's room.
R.—Landings.
l.—Washstand.
m.—Rinsing basins.
n.—Tables.
o.—Glass table for utensils.
p.—Clothes presses.
r.—Soiled-clothes chute.
s.—Cabinet for bandages.
t.—Washstand and writing table.
u.—Bandaging table.
v.—Air ducts.

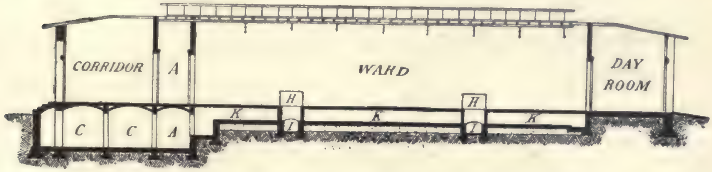


FIG. 112.

A.—Transverse corridor.
C.—Coal vaults.
H.—Radiators.
I.—Air chambers (Luftkanäle).
K.—Space or chamber for pipes for heating floor.

The general principles to be observed in the ventilation of insane asylums are much the same as those for other hospitals, but are modified by the necessity of providing for a much larger number of single rooms opening from a common corridor. As a rule, steam heating and propelling fans are used in American asylums, and in some of the larger ones the plant is an extensive one.

Figure 115 shows half basement and half first-story plan with section of the insane asylum for New Castle County, near Wilmington, Del.

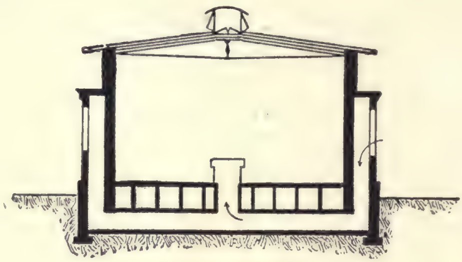


FIG. 113.

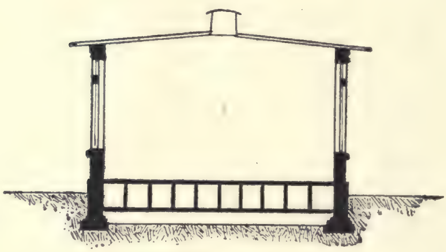


FIG. 114.

It is three stories in height, with a basement—the latter unoccupied except with a kitchen and dining rooms for the employees. The rooms for the patients are on an average 12x14 feet, with a height on the first floor of 12 feet and on the other floors of 10 feet 6 inches, with four large rooms on each floor at the extremes of each wing; the executive offices being in the center on the first and second floors while above is a large room occupying the whole floor of the center front.

All the radiators are placed in the basement halls, except some few direct radiators, marked *R* on the plans, which are either used in the halls, or dining rooms, or other large rooms with considerable glass surface, as auxiliary heaters.

Every room has a warm-air flue of 9x13 inches in its cross-section and plastered. These flues start just beneath the ceiling of the basement in the halls and terminate about 3 feet above the base-board in each room. At the opposite side of the room in the outside walls are

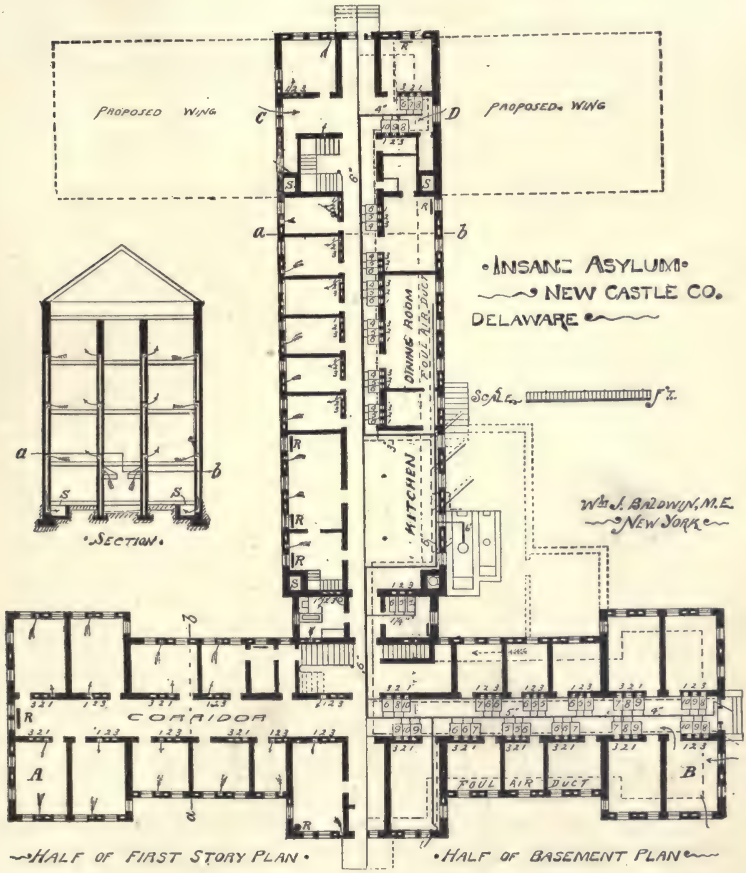


FIG. 115.

vent flues of the same dimensions, with the registers near the floor, but instead of running to the top of the house they run downward in the cold walls and terminate in horizontal foul-air ducts underneath the basement floor. These ducts which are marked *S* on the elevation

section, connect with vertical shafts *s s s* on ground plans, and with the annular space around the cast-iron boiler chimney in a similar shaft. The vertical shafts are each warmed by steam coils of 150 square feet of radiator surface arranged in coils which run around the inside of the shafts 3 inches from the walls, and covering them for a height of about 60 inches; their position being on a level with the first-story floor, and about one-quarter of the height of the stack from the bottom.

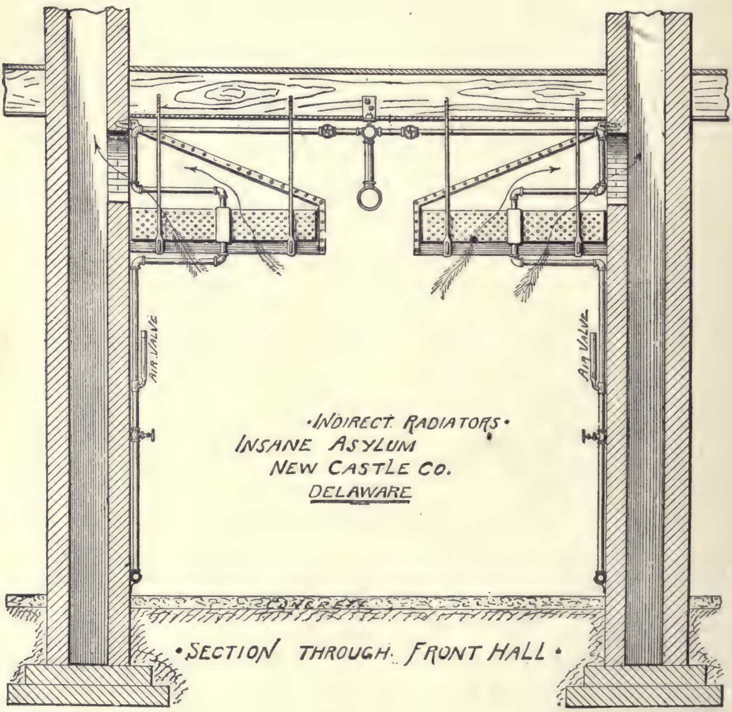


FIG. 116.

Through the front halls the hoods, Fig. 116, are opened at the bottom, the whole hall being an air duct. Air is taken in under the room *A*, first story, or through the room *B*, in the basement, as may be desired, dependent upon the direction of the wind. Here it is warmed slightly before it passes to the hall, and in the hall it again receives heat from the main and return pipes and connections. This

hallway is a reservoir of tempered air, which is drawn into the hoods by the displacement and rarification within the radiator. The inner walls, being honeycombed with flues, become heated in a short time to a temperature considerably above the air of the building, after which the air from the radiators loses no heat in its passage through these flues, and hence has a comparatively high velocity and power.

Figure 117 is a section through a rear hall, used as a passageway. In this case the hoods return at the bottom to a second opening in

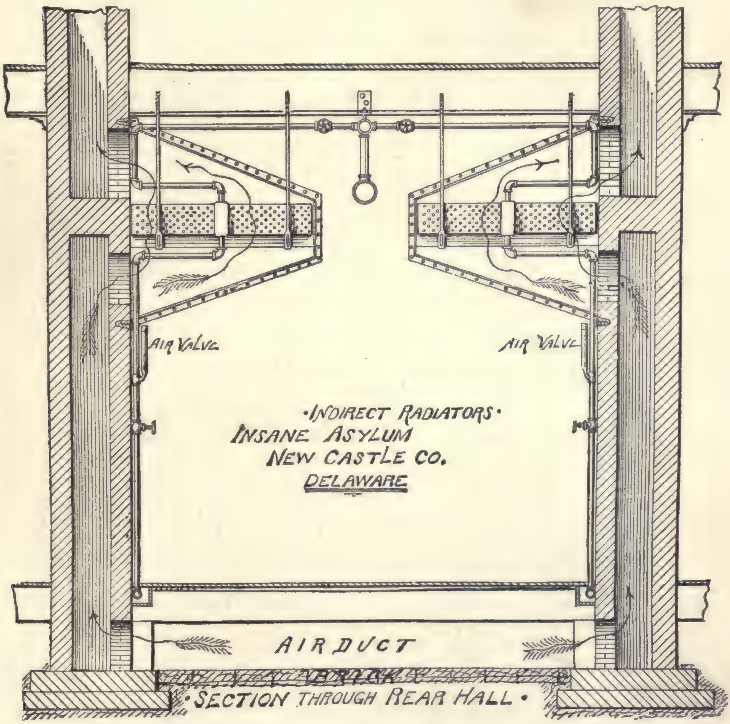


FIG. 117.

the wall, through which they receive their air from a duct underneath the hall floor.

Figure 118 is a plan of the indirect heaters and the heat flues.

For further particulars consult *The Sanitary Engineer* of December 25, 1884.

In connection with the subject of hospital ventilation may be conveniently considered that of barracks for soldiers, since much the same principles apply to each, the chief differences being that there are greater opportunities for aeration in barracks, and they require a less supply of air per head.

In past times in all armies the overcrowding of and want of ventilation in barracks has caused much disease and loss of service, and, as a rule, the more permanent and costly the buildings the more defective they have been in air supply. The cheap wooden barracks of many of

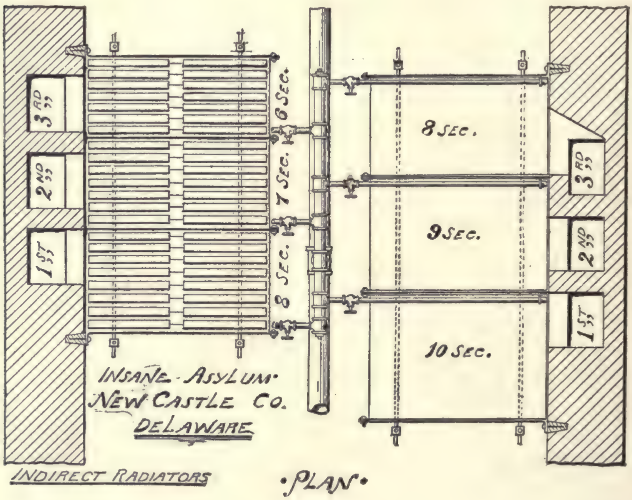


FIG. 118.

our military posts, built of unseasoned lumber and full of cracks and crevices, are in many respects healthier than casemate quarters, or than the solidly constructed buildings of brick or stone which are provided for soldiers in many other countries.

The amount of cubic space per head to be furnished in barracks is fixed by regulation in most foreign countries. For the English Army it is 600 cubic feet; for the German and Austrian armies, 527 cubic feet, with 48 square feet of floor share per man; for the French Army, 424 cubic feet for infantry, and 495 cubic feet for cavalry; for

the Belgian Army, 555 cubic feet. The Indian Army regulations call for 90 square feet of floor surface, and 1,800 cubic feet of space per man in barracks on the plains, the barracks to be two-storied, with a veranda 10 feet wide, the rooms to be 24 feet wide and 20 feet high, and not more than 24 men are to be placed in one room.

For the United States Army there are no definite regulations as to floor space or cubic space in barracks, but in the permanent barracks of recent construction at our larger posts from 600 to 800 cubic feet of air space per man are provided, and the rooms are usually 12 feet high, giving from 50 to 65 square feet of floor space per head.

These permanent barracks are heated by steam, the precise method varying at different posts. In the Cavalry Barracks at Fort Sheridan the heating is by indirect radiation, there being four inlets, each 16 inches square, for a room measuring 68'x41'x12', and containing 45 men.

The exit flues in the walls are nine in number, two 12x20 inches, two 8x12 inches and five 1 foot square each, and all these flues collect in the attic to a central shaft in which is placed an accelerating steam coil. With a velocity of between 5 and 6 feet per second at the inlets, and of 4 feet per second in the outlet flues a good air supply will be secured.

Figures 119 and 120 show first and second floor plans of half of a two-story barracks for infantry as proposed for an U. S. Army Post in process of construction by Capt. George E. Pond, A. Q. M., who has kindly furnished them with the following notes : These plans provide for 28 men in a dormitory, giving to each man 70 square feet of floor space and 840 feet of cubic space. The heating may be by direct-indirect radiators placed beneath the windows or by indirect radiation by a hot blast system, the fresh-air flues being in the outer walls. The foul-air upcast shafts *c c* are 384 square inches in cross-section, with openings both at ceiling and floor, the latter always open, the upper one controlled by a shutter hinged at the top. These shafts unite in the attic into a single shaft, which rises above the roof and is capped with a cowl. If direct-indirect heating is used an accelerating steam pipe is placed in each upcast shaft. Six Sheringham valves are placed in the outer walls near the ceiling. *A A* and *B B* are foul-air upcast shafts. *D* indicates interior wall flues which might be used for stoves in case of emergency, but which ordinarily are upcast flues having registers in place of stove-pipe openings.

Figure 121 is a floor plan of half of a double barrack, which may be called the present standard plan of the Quartermaster Department

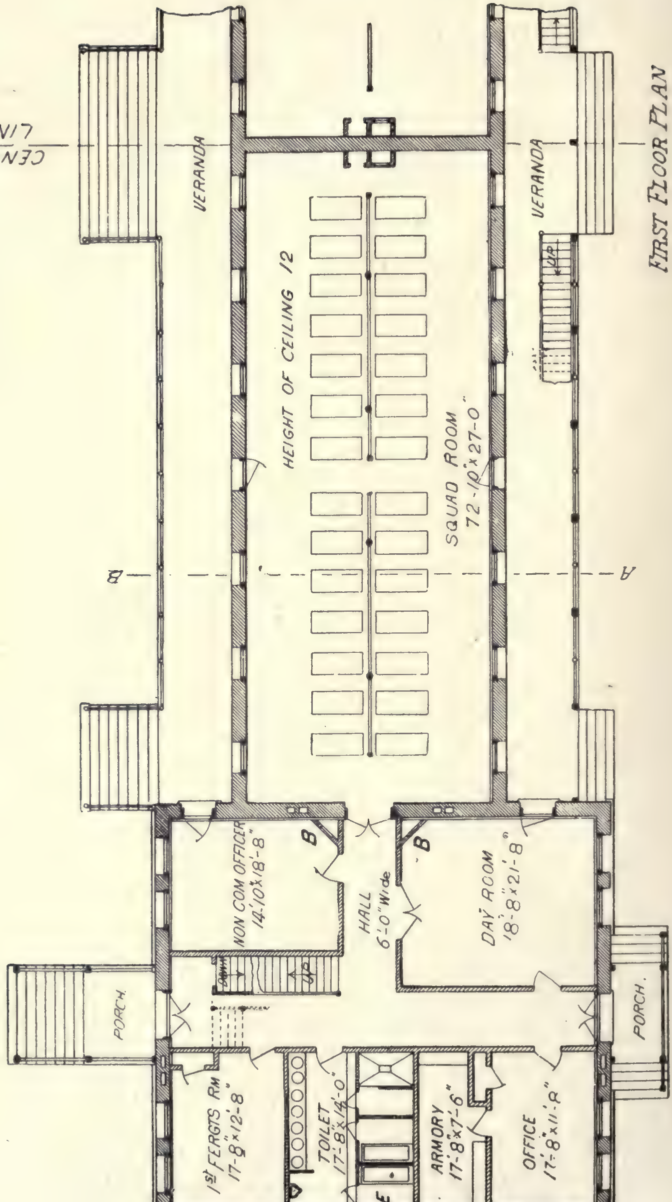

FIRST FLOOR PLAN
CENTER LINE
VERANDA
VERANDA
HEIGHT OF CEILING 12
SQUAD ROOM 72-10"x 27-0
NON COM OFFICER 14'10"x18'-8"
HALL 6'-0" Wide
DAY ROOM 18'-8"x21'-8"
PORCH.
PORCH.
1st SERGTS RM 17-8"x12'-8"
TOILET 17'-8"x14'-0"
ARMORY 17'-8"x7'-6"
OFFICE 17'-8"x11'-8"
UP
DOWN
A
B

FIG. 119.

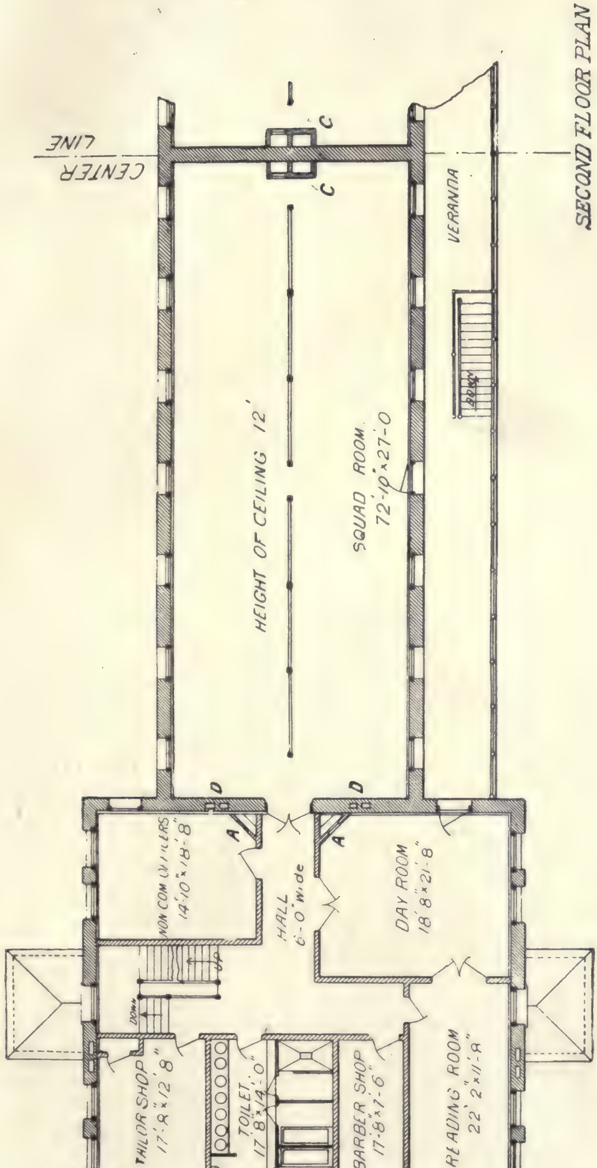

SECOND FLOOR PLAN
CENTER LINE
VERANNA
SQUAD ROOM
72'-10"x27'-0
HEIGHT OF CEILING 12'
NON COM OFFICERS
14'-10"x18'-8"
HALL
6'-0" wide
DAY ROOM
18'8"x21'8"
UP
DOWN
TAILOR SHOP
17'8"x12'8"
TOILET
17'8"x14'-0"
BARBER SHOP
17'8"x7'6"
READING ROOM
22'2"x11'8"

FIG. 120.

for permanent posts, and for which I am indebted to the courtesy of Captain Miller, A. Q. M. The upcast shafts *A B* are in the corners of the dormitory, four on each floor. *R* are radiators, part of which are direct, and part direct-indirect.

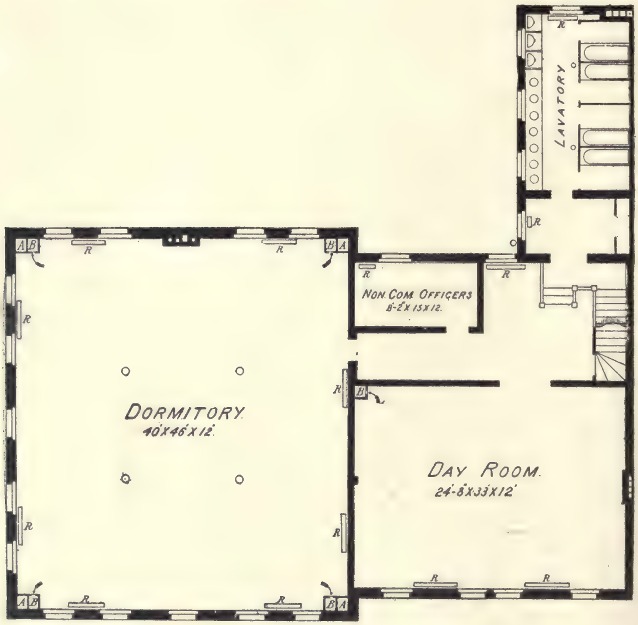


FIG. 121.

The most recent work on the construction and ventilation of barracks is "Putzeys" (*F*) and Putzeys (*E*.) Hygiène des agglomérations militaires, la construction des casernes," 8 vo., Liège, 1892—with an atlas of 10 plates relating mainly to Belgian barracks.

CHAPTER XV.

VENTILATION OF HALLS OF AUDIENCE AND ASSEMBLY ROOMS. THE HOUSE OF PARLIAMENT. U. S. CAPITOL. THE NEW SORBONNE. THE NEW YORK MUSIC HALL. THE LENOX LYCEUM.

SOME of the most difficult problems in ventilation are met with in large assembly rooms, or halls of audience, including legislative halls, churches, theaters, music halls, etc. These may be divided into three classes, each presenting certain peculiarities which have an important bearing upon the arrangements for their heating and ventilation.

The first class includes the assembly halls used by legislative bodies; the second, the majority of churches and theaters, and the third, lecture rooms and other assembly rooms located in the second or third stories of large buildings, in which the rooms below are occupied for other purposes, and are not available for heating and ventilating apparatus.

Legislative assembly halls differ from most other halls of audience in that they may at times be occupied for many hours continuously. The number of persons in them is liable to vary greatly and suddenly and it is desirable that a person speaking on any part of the floor shall be distinctly heard by persons on any other part of the floor. Expense of construction and maintenance is usually a very secondary matter.

No such hall has been yet constructed which has given at all times satisfactory results to all of the legislators who have used it, and whatever system has been tried, the rule is that in a few years at latest the complaints become so numerous and emphatic that a special investigation is ordered and changes of some kind are recommended. The complaints are, for the most part, made with regard to unpleasant odors, to excessive heat, to disagreeable draughts of cold air, and to interference with the acoustic properties of the hall.

Probably no legislative hall of assembly has been the subject of more complaints, or of more experimental changes, than have those of

the Houses of Parliament in London. The present system of ventilation in the Houses of Parliament is a modification by Dr. Reid, Sir G. Gurney, and Dr. Percy, of the system adopted by the committee of 1840, appointed to inquire into the causes of the frequent complaints from members of bad ventilation and defective communication of sound.

Ventilation by exhaustion by heated shafts has been used in the Houses of Parliament until recently, when a plenum system has been adopted.

General diffusion of the fresh air being the desideratum, the floors of the houses are formed of cast-iron gratings, which are overlaid (in the House of Lords) with hair carpet and with coarse hemp netting (in the House of Commons). These gratings, forming the ceilings of the equalizing chambers, allow of the free admission of a large quantity of air with a perfect absence of draught.

Below the equalizing chambers, and communicating with them by *grated* openings, is another chamber, containing the heating arrangement or other apparatus for such treatment of the air as the state of the atmosphere may necessitate. The whole of the space occupied by the heaters is surrounded by a gauze screen, which acts as a filter to arrest any coarse particles of dust, etc., that would otherwise pass into the house. In summer the air is more or less freed from dust, by passing through fine water spray.

The quantity of the air passing is regulated by a sliding door or valve, placed in the foul-air exit, above the ceiling of the house. This is actuated by hydraulic arrangement, and is under the control of the attendant stationed in the air chamber under the house.

The panels of the ceilings are raised, leaving spaces around their edges, through which the foul air from the houses is drawn off up to the upcast shafts.

In the Commons each set of gas-burners is connected by a vertical tube with a main flue (running the length of the ceiling), in connection with the upcast shaft, into which the products of combustion pass.

It was formerly considered that by drawing the air from the top of one of the towers a purer supply would be obtained than if taken from the ground level. This has (in London), however, proved to be a fallacy; the air thus obtained was the most contaminated with smoke and other impurities.

In the House of Commons the air inlets were formerly placed in the "star" and "commons" courts, but now consist of 35 openings on the terrace, each having an area of a little over 9 square feet.

During the hottest weather the air has been cooled by passing it over blocks of ice placed on wooden racks in the airways.

The surface of the ice exposed, however, being small in proportion to the volume of air passing, the temperature was but slightly reduced, usually not more than one degree (1°), yet the air thus treated, it was thought, produced a sensation of freshness, which possibly might be due to the condensation by the ice of the excess of moisture present. This was particularly noticed on one occasion, when the temperature of the air was nearly the same before and after passing the ice.

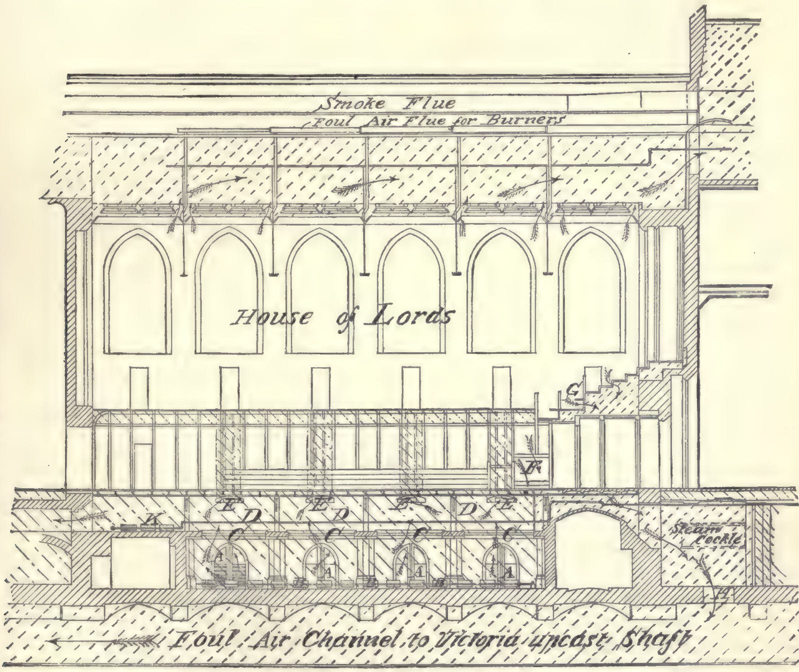


FIG. 122.—SECTIONAL ELEVATION OF THE HOUSE OF LORDS SHOWING WARMING AND VENTILATING ARRANGEMENTS.

The fresh air, drawn through a passage in which are spray jets for moistening and cooling it when desirable, is forced by an air propeller through a canvas screen having an area of about 600 square feet, after which, in case of fog, it passes through a loose layer of cotton batting, and thence to the warming chamber on the floor of which the heating batteries *B B*, are arranged in four equidistant and parallel rows.

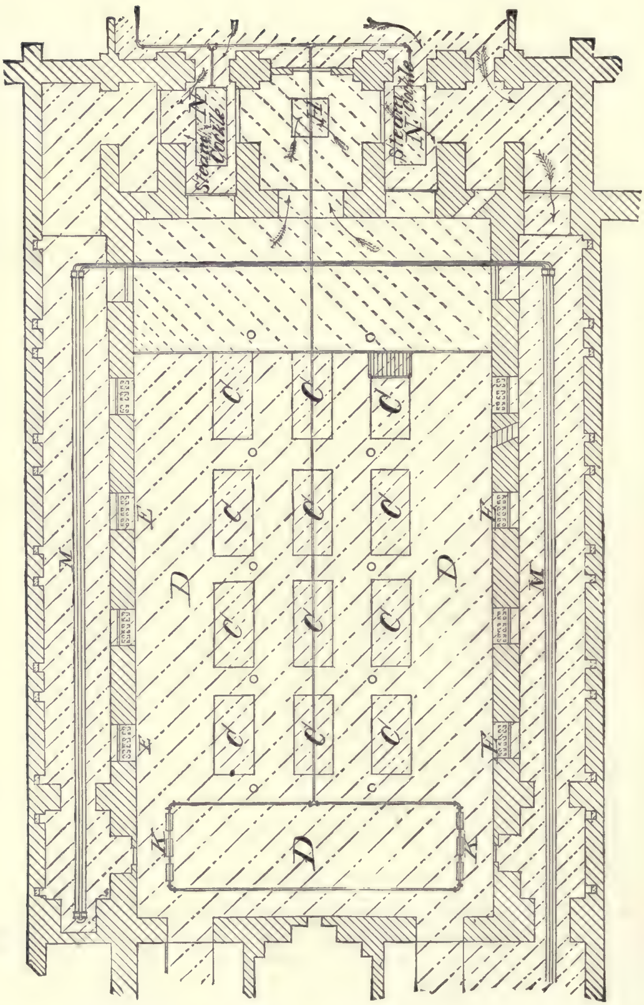


FIG. 123.—HORIZONTAL SECTION THROUGH EQUALIZING CHAMBER OF HOUSE OF LORDS.

The heated (or cooled) air ascends through gratings C C, in the openings to the equalizing chamber D, from whence it is distributed to the

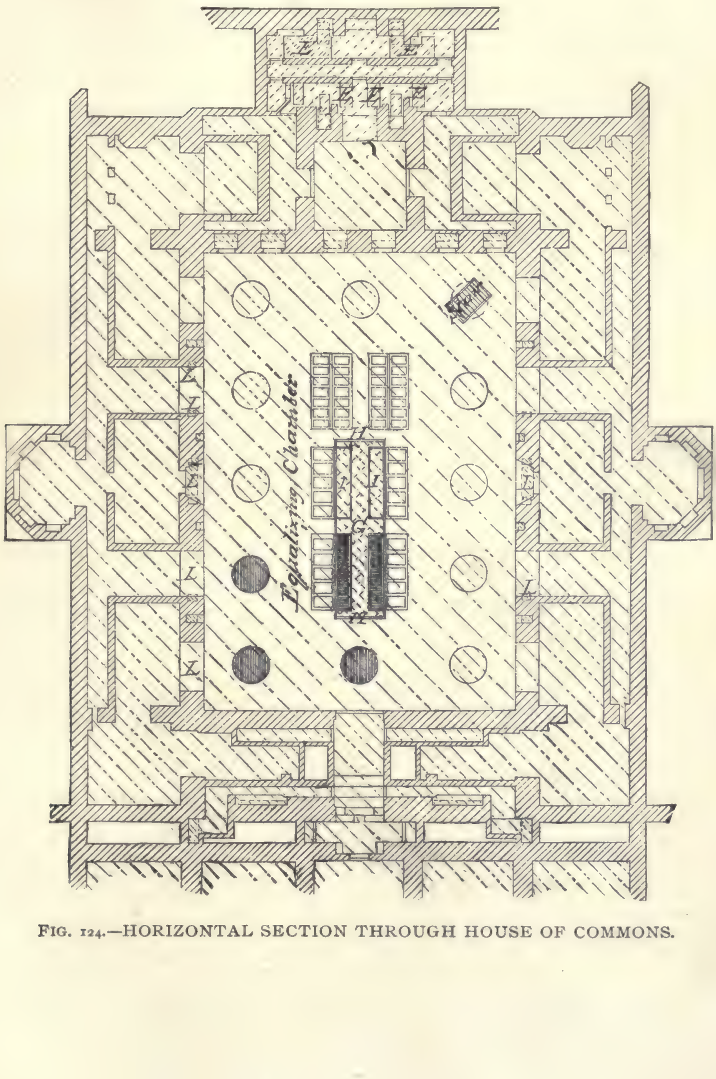


FIG. 124.—HORIZONTAL SECTION THROUGH HOUSE OF COMMONS.

house (through the grated floor) and to the galleries (by the openings and flues *E E*).

The vitiated air is drawn off through the openwork in the ceiling to the foul-air space, in communication with the up-cast shafts, and also through openings behind the bar *F*, to the Victoria tower by the down-pull *H*, as shown on the drawing.

Figure 123 shows a horizontal section through the equalizing chamber of the House of Lords. The lettering is the same as on Fig. 122.

The batteries *K*, are for heating that part of the house immediately beneath the throne ; *M* are steam pipes for heating the air supply to the division lobbies.

In a report of a Select Committee on the Ventilation of the House of Commons made in 1891, it is recommended that the size of the intake of fresh air be increased, a powerful air propeller be provided and additional facilities for the entrance of fresh air be obtained both for the hall and for committee rooms.

The use of large aspirating chimneys instead of fans as a means of ensuring the movement of air, are not in accordance with the views of modern engineers, or with their ordinary practice.

Let us now compare with the above the arrangements for ventilating and warming the halls of the Senate and of the House of Representatives in the Capitol at Washington. These have been the subject of nearly as many complaints, investigations and reports as have the Houses of Parliament, but the actual changes made have not been so numerous.

The first of the Congressional documents relating to this subject, which have now any interest or value, is what is commonly called the Wetherell Report, being Executive Document 100 of the House of Representatives of the first session of the 39th Congress, dated May, 1866.

This document contains briet reports by Mr. Walter, the architect, and by Professor Joseph Henry, of the Smithsonian Institution, transmitting a long report by Dr. Charles Wetherell, giving the results of experiments and tests made by him to determine the proportions of carbonic acid present in the hall under various circumstances.

These results showed that the amount of carbonic acid present was relatively very small, and that the gas was very uniformly diffused throughout the hall.

The report gives an extensive and valuable series of tables comparing these results with those obtained by other investigators in lecture rooms.

THE FOLLOWING TABLE GIVES SOME OF THE RESULTS REPORTED BY DR. WETHERELL.

No. of Analysis.	Place of Observation.	Date.	Temperature of Air, Fahr. °.	Relative Humidity.	Carb. Acid per 10,000 per Vol.	
					Experiments	Mean
		1864.				
1.	Smithsonian laboratory	June 27.	90.5	47	...	...
2.	Capitol, N. E. portico	"	86.9	51	...	...
3.	Senate, S. E. corner, over ventilator	"	86.	50	...	...
4.	Senate, opposite chair	"	82.4	77	...	...
5.	Senate, ladies' gallery, S. E. corner	"	84.2	58	...	...
6.	Senate, Sergeant-at-Arms' office	June 28.	74.3	[illegible]	...	...
7.	Senate, S. E. corner, over ventilator	"	77.	34	...	...
8.	Senate, opposite chair	"	77.	34	...	...
9.	Senate, ladies' gallery, S. E. corner	"	77.9	32	...	...
10.	Smithsonian laboratory	"	77.9	32	...	...
11.	" "	June 29.	78.8	30	...	...
12.	Senate, S. E. corner ventilator	"	77.9	34	...	...
13.	Senate, opposite chair	"	78.8	36	...	...
14.	Senate, ladies' gallery, S. E. corner	"	78.8	36	...	...
15.	Capitol, N. E. portico	"	78.8	30	...	...
16.	Smithsonian laboratory	June 30.	77.0	54	...	...
17.	Capitol, main portico	"	78.8	48	3.345	...
18.	Capitol, main portico, 2d experiment	"	78.8	48	3.172	3.258
19.	House of Representatives, N. W. corner	"	78.8	62	6.793	...
20.	House of Representatives, 2d experiment	"	78.8	62	4.185	5.489
21.	House gallery, behind clock	"	78.8	62	4.902	...
22.	House gallery, 2d experiment	"	78.8	62	4.147	4.525
23.	Smithsonian laboratory	July 2.	88.2	51	...	...
24.	" "	"	78.8	80	...	...
25.	Capitol, N. E. portico	"	84.2	71	...	...
26.	Senate,† over S. E. corner ventilator	"	82.4	74	...	...
27.	Senate, six feet from ventilator	"	84.2	71	...	...
28.	Senate, opposite chair	"	84.2	71	...	...
29.	Senate, over opposite ventilator	"	82.4	71	...	...
30.	Senate, six feet from ventilator	"	84.2	71	...	...
31.	Senate, N. W. corner	"	84.6	71	...	...
32.	Senate, over side ventilator	"	82.4	74	...	...
33.	Senate, ladies' gallery, S. E. corner.	"	84.2	68	...	...
34.	Senate, stairs to gallery, opposite ventilator	"	80.6	74	...	...
		1865.				
35.	Senate, post-office, near a closed window	Jan 24.	61.9	46	...	...
36.	Senate, post-office, on mantelpiece	"	70.2	32	...	...
37.	" " " "	"	70.9	31	...	...
38.	" " " "	"	70.5	33	...	...
39.	Senate, ladies' gallery, near reporters' gallery	"	72.0	27	...	...
40.	Senate, ladies' gallery, near diplomatic gallery	"	72.3	27	...	...
41.	Senate, air entering fan	"	29.8	56	...	...
42.	Senate, external air, north portico	"	31.3	58	...	...
43.	Smithsonian Institution, external air	Feb. 8.	33.8	65	2.722	...
44.	" " " "	"	33.8	65	2.685	...
45.	" " " "	"	33.8	65	2.719	2.709
46.	Senate, air entering fan	Feb. 9.	30.6	55	2.700	...
47.	Senate, air entering fan, 2d experiment	"	30.6	55	2.659	...
48.	Senate, air entering fan, 3d experiment.	"	30.6	55	2.587	2.649
49.	Senate, level desks, S. E. corner	"	70.9	20	5.491	...
50.	Senate, level desks, 2d experiment	"	70.9	20	5.979	5.735
51.	Senate, diplomatic gallery	"	68.	21	3.871	...
52.	Senate, diplomatic gallery, 2d experiment	"	68.	21	4.085	3.978
53.	Senate, illuminating loft, N. W. corner, over ventilator	"	64.	27	4.733	...
54.	Senate, illuminating loft, N. W. corner, over ventilator, 2d experiment	"	64.	27	4.443	4.588
55.	Smithsonian Institution, dining room of the secretary.	Feb. 15	69.8	44	4.340	...
56.	House of Representatives, air entering fan	Feb. 16.	35.2	100	2.637	...
57.	House of Representatives, air entering fan, 2d experiment	"	35.2	100	2.785	2.711
58.	House of Representatives, level of desks, N. W. corner.	"	72.7	46½	3.495	...
59.	House of Representatives, level of desks, N. W. corner, 2d experiment	"	72.7	46½	3.608	3.552

DR. WETHERELL'S TABLE.—(*Continued.*)

No of Analysis.	Place of Observation.	Date.	Temperature of Air, Fahr. °.	Relative Humidity.	Carb. Acid per 10,000 per Vol.	
					Experiments.	Mean.
60.	House of Representatives, diplomatic gallery...	Feb. 16	70.9	46½	3.913	... ..
61.	House of Representatives, diplomatic gallery, 2d experiment ...	"	70.9	46½	3.157	3.535
62.	House of Representatives, illuminating loft, N. E. corner...	"	68.4	48	4.065	....
63.	House of Representatives, illuminating loft, 2d experiment ...	"	68.4	48	3.751	3.908
64.	Dwelling, 311 F Street, bed room, 2d story, front....	Feb. 17.	65.2	57	2.650	.. ...
65.	" " " " " " "	Feb. 18.	68.4	46	5.189	... ..
66.	Senate, air entering fan...	Feb. 24.	37.4	67	2.360	.. ..
67.	Senate, air entering fan, 2d experiment ...	"	37.4	67	2.825	......
68.	Senate, air entering fan, 3d experiment...	"	37.4	67	2.758	1.648
69.	Senate, level of desks, S. E. corner...	"	66.9	31	4.275	..
70.	Senate, level of desks, 2d experiment ...	"	66.9	31	4 839	4,557
71.	Senate, reporters' gallery ...	"	70.9	28	4.814	.....
72.	Senate, illuminating loft, near ventilator...	"	72.3	28½	7.269	......
73.	Senate, illuminating loft, near ventilator, 2d experiment ...	"	72.3	28½	7.355	7.312
74.	House of Representatives, air entering fan ...	Feb. 25.	36.7	93	... ..	.....
75.	House of Representatives, S. W. corner, outer circle of desks...	"	69.4	43	......	.....
76	House of Representatives, center circle of desks......	"	69.4	43	..	..
77.	House of Representatives, Hon. Mr. Baily's desk	"	69.8	41	......	... ..
78.	House of Representatives, S. E. corner, outer circle of desks ...	"	69.8	41	......	..
79.	House of Representatives, air entering fan...	Feb. 27.	51.4	49	......	......
80.	House of Representatives, S. W. corner (as above)...	"	71.6	37	... ..	. ..
81.	House of Representatives, center (as above)...	"	71.6	35	... ..	......
82.	House of Representatives, Hon. Mr. Baily's desk ..	"	71.6	35	......	.. ..
83.	House of Representatives, S. E. corner (as above)....	"	71.6	35	... ..	.. ..
84.	Dome, top of balustrade of tholus ...	Mar	64.2	34	2.801	... ..
85.	Dome, top of balustrade, 2d experiment...	"	64.2	34	2.901	2.851
86.	Capitol, first platform steps, main east portico, 4 feet 4⅔ inches above ground...	"	65.	35	2.686	. ....
87.	Secondary public school, Miss Mills...	Mar. 31.	68.	60	9.342	.. ..
88.	Primary public school, Miss Robinson. ...	"	68.	60	10 574	.. ..
89.	Primary public school, Miss Hubbard...	"	68.	60	9.454	......
90.	Public school, main intermediate, 1st division, Mrs. Rodier, air entering from teacher's desk...	"	74.	63	17.184	... ..
91.	Public school air from north side of room...	"	75.	60	12.803	.....
92	Public school, air from south side of room : ...	"	85.	44	12.680	....

The chief point of controversy in the various schemes which have been proposed for the ventilation of these and other assembly halls is as to whether the general direction of the ventilating currents should be upward or downward. We have commented briefly on this point in speaking of outlets and inlets, but it requires special consideration in this connection. The arguments which have been urged in favor of the down-draught system are that impurities in the air collect mainly in the strata near the floor, that it is much easier to avoid unpleasant draughts and the entrance of dust into the hall when the air passes out through the floor than when it passes in through it, and that a

more uniform distribution of the incoming air with less interference with the transmission of sound is thus secured. The first of these arguments is based on the erroneous idea that carbonic acid is the dangerous impurity to be gotten rid of—and that it accumulates near the floor because it is heavier than the air. The other reasons given are good so far as they go—and should be considered in connection with the arguments in favor of an upward system for a large hall, the center of which is occupied by a number of people. These arguments are summed up in the following extracts from Report No. 119 of the Documents of the House of Representatives of the second session of the 45th Congress, presented in 1878 by a board consisting of Professor Henry, of the Smithsonian Institution; Colonel Casey, of the U. S. Engineers; Mr. Clarke, the architect of the Capitol; Mr. Schumann, C. E., and Dr. J. S. Billings, U. S. A.:

"The problem of ventilation of the hall may be stated as follows: How to introduce and distribute from 30,000 to 60,000 cubic feet of fresh air per minute—corresponding to from 600 to 1,200 occupants—and to do this in such a way that the occupants shall not be annoyed by heat, cold, or currents of air.

"Even were this done, perfect ventilation would not be obtained, for this would only provide for dilution of the impure air, while in perfect ventilation the impurities are not so diluted, but completely removed as fast as formed, so that no man can inspire any air which has shortly before been in his own lungs or in those of his neighbor.

"To secure such ventilation as this, horizontal currents must be avoided, and all the air in the room should be made to move directly upward or directly downward. It is utterly impossible to thoroughly ventilate such a hall as that of the House, if fully occupied, by any so-called natural ventilation by means of doors and windows.

"The relative merits of the upward *versus* the downward systems of ventilation in large halls in which the center of the room is occupied by a number of people, may be estimated from the following considerations:

"*First.*—The direction of the currents of air from the human body is, under ordinary circumstances, upward, owing to the heat of the body. The velocity of these currents is small, but it may be estimated as being certainly not less than 1 inch per second. This current is an assistance to upward and an obstacle to downward ventilation.

"*Second.*—The heat from all gas flames used for lighting tends to assist upward ventilation, but elaborate arrangements must be made to prevent contamination of the air by the lights, if the downward method be adopted.

"*Third.*—In large rooms an enormous quantity of air must be introduced in the downward method, if the occupants are to breathe pure and fresh air. The whole body of air in the room must be made to move uniformly downward; for if at any point this be not the case, the products of respiration will rise at those points, and, diffusing, contaminate the air which is coming down

to be breathed. The uniform rate of descent should certainly be not less than 3 inches per second, in order to overcome the ascensional tendency of the currents from respiration, the heat of the body, etc., which implies that, for every 100 square feet of floor area, at least 1,500 cubic feet of fresh air are to be brought in per minute. As the floor of the hall and galleries of the House contain 12,927 square feet, it follows that the amount of fresh air required would be 193,500 cubic feet per minute, or about three times the amount which is found to give satisfactory results with the upward method.

"*Fourth.*—In halls arranged with galleries the difficulty of so arranging downward currents that on the one hand the air rendered impure in the galleries shall not contaminate that which is descending to supply the main floor below, and, on the other hand, the supply for the floor shall not be drawn aside to the galleries, is so great that it is almost an impossibility to effect it.

"For these and other reasons, the board are of the opinion that the upward method should be preferred. In the upward method there are two special difficulties to be met in halls of this kind. The first is dust derived mainly from the shoes of the occupants. This, becoming dry, is ground into fine powder, some of which is kept floating in the air by the upward currents. By careful supervision, and by the use of carpets which can be easily detached and frequently shaken, as is done in the English House of Parliament, this evil can be so much mitigated as not to be noticed.

"The second difficulty is due to the discomfort produced by perceptible currents of air. The cause of this is insufficient area and improper position of the openings for the admission of fresh air. If the area of openings be too small, the air must pass through them with too great velocity in order to obtain the required quantity. In a hall liable to be so fully occupied as this, there are few points at which fresh-air openings can be placed the current from which will not impinge on some part of the body of some occupant, and if it does so impinge the velocity should not exceed 2 feet per second, in order to avoid sensations of draught. The supply of air for the House should be, as we have seen, from 600 to 1,200 cubic feet per second, whence it follows that the total area of openings should be nearly 500 square feet. It is desirable to diminish the effect of these openings as much as possible by placing at least a part of them at points where the currents will not reach a person for several feet, or until they have become somewhat diffused. In attempting to effect this it is very important to remember the law of the adhesion of gases to surfaces, and it is from omission to do this that a large part of the discomfort of members of the House has arisen. It should be distinctly understood that the board states these general principles only as applicable to large assembly halls where a number of people are gathered in the center of the room, for under other circumstances some of them do not hold good."

In this connection the report made in 1891 by M. Trélat on the ventilation of the French Chamber of Deputies is of interest. This chamber is much overcrowded, there being but 30 centimeters square of floor space to each deputy. The air is delivered by fan propulsion at the ceiling and is taken out at the floor, giving a downward system

of ventilation. The apparatus is powerful enough to change the air in the chamber every six minutes, but it can only be worked slowly, owing to the draughts produced, and the air vitiated by respiration is brought back to be reinhaled. M. Trélat, as the result of his observations, emphatically condemns downward ventilation for a hall of this kind, and advises a radical change.

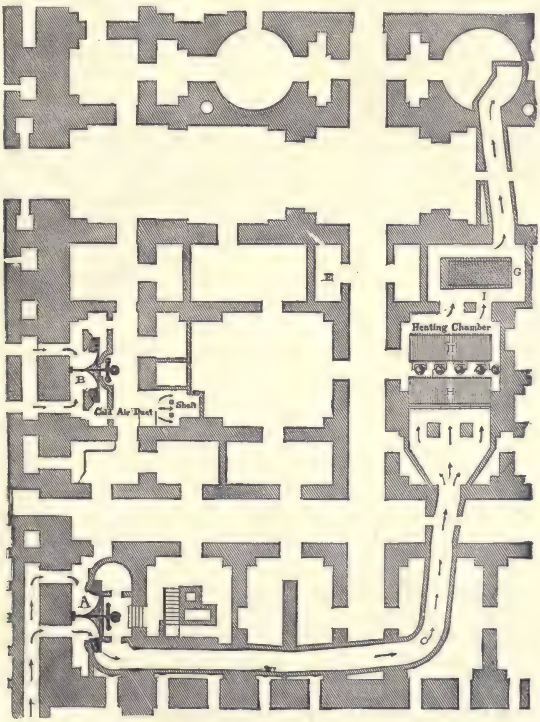


FIG. 125.—PLAN SHOWING AIR DUCTS, ETC., IN CONNECTION WITH HEATING APPARATUS, SOUTH WING, U. S. CAPITOL.

A.—Main fan for hall.
B.—Small fan for committee rooms.
G.—Evaporator and mixing chamber.
H.—Heating coils.

The small fan *B*, shown in Fig. 125, was originally connected with the space immediately over the hall, it being supposed that at times the wind was deflected from the central dome in such a way as to blow down through the louvered openings into this attic, which openings

were the only means provided for the escape of foul air. The result of the use of this aspirating fan, in addition to the rarefaction of the air produced in the hall by the force of the aspirating shaft or chimney, was such that there was a constant tendency for air to flow into the hall from the surrounding corridors, and whenever a door was opened the direction of the current through it was always inward. These currents had such strength that it was found necessary to place screens opposite the doors to break their force.

This aspirating fan is now connected with the corridors, as shown in the figure, and the result has been very satisfactory.

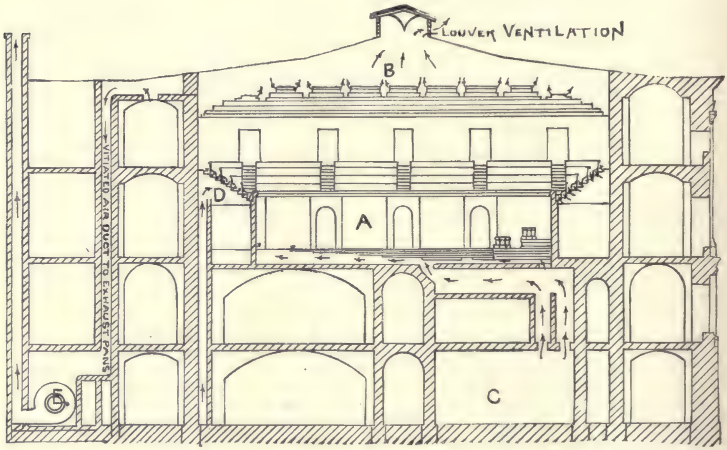


FIG. 126.—TRANSVERSE SECTION THROUGH SOUTH WING, U. S. CAPITOL.

A.—Main hall.
B.—Space over hall.
C.—Main fresh-air duct.
D.—Fresh-air supply to galleries.
E.—Exhaust fan.

The total area of clear opening for the admission of fresh air on the floor of the hall is about 300 square feet and in the galleries about 125 square feet. The total area of openings in the ceiling for the discharge of foul air is about 670 square feet, being three times as much as is necessary. This is, however, a matter of minor importance, since the amount of flow is practically controlled by the louvers.

Through the courtesy of Mr. Lannan, the engineer of the House, I am able to present a table of data showing the working of the apparatus during the month of February, 1892.

OBSERVATIONS RELATING TO THE MOVEMENTS OF AIR, ITS TEMPERATURE, RELATIVE HUMIDITY, ETC., AT THE HOUSE OF REPRESENTATIVES DURING THE MONTH OF FEBRUARY, 1892.

Date.	Temperature.							Hygrometer.		Revolutions of the Fan per Minute.	Air Movement.				Average Number of Persons in the Hall.	Cubic Feet of Air per Minute per Person.	Wind.		Weather.	Barometer.	
	Outside at			In the Hall.			At Louvers Above Ceiling During Session.	Dry Bulb.	Relative Humidity.		In the Duct.		At Louvers Above Ceil'g.				Velocity in Miles per Hour.	Direction.			
	M 12	P.M 2	P.M 4	During Session. Hig't	During Session. L'w't	Lowest at Night.					Velocity in Feet per Minute.	Volume Cubic Feet per Minute.	Velocity in Feet per Minute.	Volume in Cubic Feet per Minute.							
1	44	50	54	70	68	62	70	65	73	42	400	30,000	290	29,000	500	60	6	S.	Cloudy	30.30	
2	53	57	58	71	70	67	71	68	70	41	390	29,250	285	28,500	450	65	6	S.	"	30.10	
3	45	45	45	70	70	68	70	69	70	42	440	33,000	310	31,000	500	66	10	N.W.	"	30.20	
4	46	46	47	70	70	67	70	65	49	46	450	33,750	315	31,500	500	67	18	N.W.	"	30.40	
5	33	33	33	71	69	67	90	68	51	41	470	35,250	340	34,000	600	58	18	N. E.	Snow	30.20	Outer row gas-lighted.
6	35	36	40	70	70	63	71	68	38	45	450	33,750	315	31.500	550	60	3	W.	Cloudy	30.50	
7	..	..	..	..	..	..	..	..	..	..	...	......	...	.....	...	..	..	......	....	..	
8	55	59	60	70	69	63	72	68	51	49	430	32,250	320	32,000	600	53	14	S.	Cloudy	30 0	
9	45	46	46	70	69	65	71	68	51	46	450	33,750	320	32,000	600	56	18	N.W	"	30.20	
10	42	45	45	70	69	65	72	67	50	45	470	35,250	360	36,000	550	64	7	S.	"	30.20	
11	46	46	48	71	69	65	90	70	53	45	460	35,000	350	35,000	500	70	17	W.	"	29.66	Outer row gas-lighted.
12	29	30	32	70	69	55	70	67	46	50	550	41,250	440	44,000	600	68	25	N.W.	"	29.80	
13	28	32	35	70	69	60	70	70	53	45	450	33,750	330	33,000	500	67	10	W.	"	30.20	
14	..	..	.	..	..	..	..	..	..	..	...	...	...	......	...	..	..	......	... ...	.....	
15	46	42	45	70	69	65	71	69	48	46	450	33,750	320	32,000	600	56	22	N.W.	Clear	30.30	
16	38	40	44	71	69	63	71	69	48	47	470	35,250	315	31,500	500	70	10	N.W.	"	30.60	
17	32	38	38	70	69	63	71	70	44	50	500	37,500	380	38,000	650	57	10	N.	"	30.80	
18	41	60	52	70	69	65	72	68	47	45	450	33,750	325	32,500	550	60	7	S. E.	"	30.40	
19	52	52	52	70	70	51	71	68	51	47	440	33.000	300	30 000	500	66	9	E.	Cloudy	30.40	
20	..	..	..	..	..	..	..	..	..	.	...	... ..	...	. ..	...	..	..	......	......	....	
21	..	..	..	..	.	..	.	..	..	..	...	.. .	...	.....	...	..	..	.. ..	.. . .	.. .	
22	..	..	..	..	..	..	..	.	..	..	. .	.....	...	.. ..	.	..	..	.. ..	... ..	... .	
23	..	..	..	..	..	..	..	..	..	..	..	. ..	...	.. ..	...	..	..	.. .		.....	
24	43	43	44	70	69	66	70	68	48	48	490	36,750	340	34,000	600	61	7	N.	Cloudy	30.50	
25	46	46	46	70	69	66	70	70	53	48	475	33,625	320	32,000	550	64	4	N.W.	Rain	30.40	
26	52	53	54	71	70	67	71	69	56	45	410	30,750	300	30,000	600	51	12	N.	Cloudy	30.40	
27	49	51	51	70	69	66	71	68	58	46	490	36,750	400	40,000	600	61	20	N. E.	"	30.55	
28	..		..	..	..	..	..	..	..	..	...	.. ...	...	.....	...	..	..	......	.. ....	. ...	
29	41	41	41	69	68	65	71	68	60	52	470	35,250	400	40,000	600	58	23	N. E.	Rain	30.10	

Average relative humidity.................. 53
" revolutions of fan per minute 46
" volume of air moved forward by each revolution.. ... 746

Average volume of air carried to the hall per minute 34,316
" " " " " " " per person 62
" " " removed from the hall per min. " 60

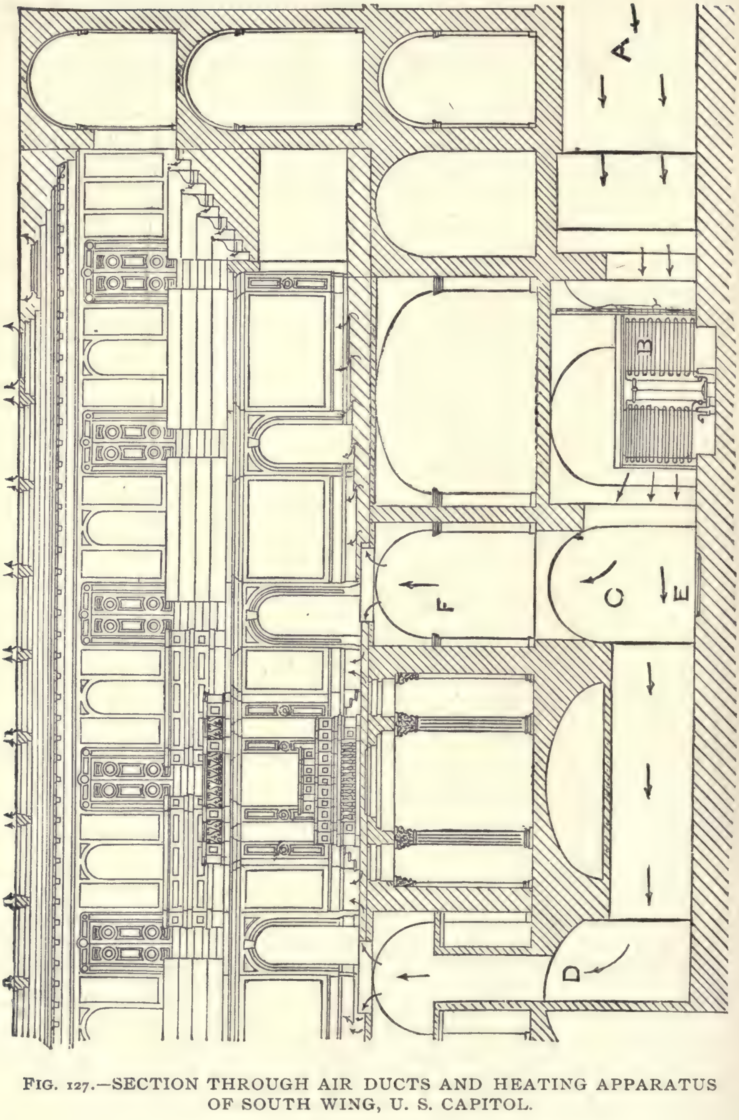


FIG. 127.—SECTION THROUGH AIR DUCTS AND HEATING APPARATUS OF SOUTH WING, U. S. CAPITOL.

A.—Cold-air duct.
B.—Heating coil.
C.—Mixing chamber.
D.—Fresh-air shaft.
E.—Evaporator.
F.—Fresh-air shaft.

The results obtained are still better demonstrated by the results of some air analyses, made at the request of the writer, in January, 1880, by Dr. Charles Smart, U. S. A. After the House had been in session 3½ hours, with 250 persons present on the floor and 300 in the gallery, the proportion of carbonic acid present in the air at the level of the desks was found to be 7.67 parts per 10,000.

As a portion of this carbonic acid was derived from the underground duct, the amount of carbonic impurity is really not excessive. It shows, however, that the distribution of the fresh air in the hall is not as prompt and uniform as it should be, since with the amount of air passing into and out of the hall, and the number of persons present, the amount of carbonic impurity present should not have exceeded 6.3 parts per 10,000.

The hall of the House of Representatives is a room 139x93 feet, and 36 feet high, with galleries and retiring rooms beneath them, which reduce the area of the floor to 113x67 feet. This room is surrounded by corridors and committee rooms, so that all its walls are internal walls, and it is lighted entirely from above by a skylight which extends over the greater part of the hall. Beneath it is a basement story, 20 feet high, and beneath this again is the cellar or crypt, in which the ventilating apparatus is placed. The plan of this cellar floor is given in Fig. 125, for which, as well as for the other illustrations of the hall, I am indebted to the courtesy of Mr. Edward Clarke, the architect of the Capitol. The fresh-air supply is taken from a point on the lower terrace about 200 feet from the building, by means of a low tower open at the top and a tunnel, to the large fan.

The fan is 16 feet in diameter and was intended to supply at 60 revolutions per minute 50,000 cubic feet of air against a resistance of about half an inch of water column, and when running at from 100 to 120 revolutions to give 100,000 cubic feet of air, which was supposed to be the maximum amount required.

The report on the ventilation of the Senate Chamber, contained in Senate Report No. 880, 52d Congress, first session, presented July 5, 1892, shows that the chief cause of complaint of the Senators is not impurity but the temperature, which is usually from 70° to 71° F., being that which is most agreeable to the majority of the occupants. A certain number would prefer 67° or 68°, and three or four would like 75°, and thus if the temperature is to be kept uniform there will always be complaints. It would, of course, be possible to vary the temperature in different parts of the chamber, or even to so introduce the air that each Senator could regulate the temperature in his own

immediate vicinity to suit himself, but this would be expensive, and would injure the acoustic properties of the hall.

It has been shown by experiments that the direction, intensity and form of sound waves are modified when they pass through currents of air of varying density, so as to produce indistinctness of the sound, even if it is loud enough to be heard. If the direction from the speaker

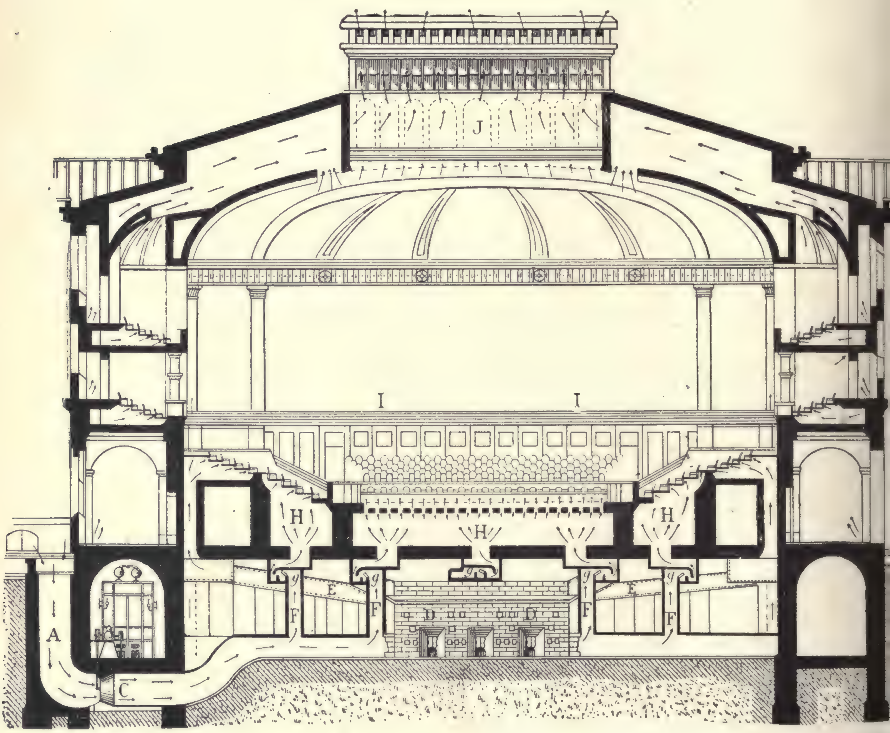


FIG 128.

towards the points where it is desirable that he should be distinctly heard nearly coincides with the direction of the ventilating air currents, and if these are of nearly uniform temperature, the audience will obtain the best results; but if the sound waves have to cross ascending currents of air of a different temperature, and therefore of different

density from that of the surrounding air, the sound will be made more or less confused and indistinct.*

If the position of the speakers in the hall be tolerably uniform, as is the case in churches and theaters, the direction of the ventilating currents can be arranged without much difficulty to give the audience the best chance of hearing them distinctly, but in such legislative halls as those of the Senate and House of Representatives, where it is the custom that each speaker speaks from any part of the floor which he may happen to select—a vertically ascending column or sheet of warm air at any point within the circle of seats will sometimes prevent the speaker from being distinctly heard in certain parts of the hall.

From a report made by M. Trélat in 1891 it appears that the ventilation of the French Chamber of Deputies is in a more unsatisfactory condition than that of the English or American National Assembly Halls. The French chamber is overcrowded, the fresh air is delivered at the top of the room, and the currents of air are strong and varied causing great discomfort. The only remedy is to build a new and larger hall.

Figure 128 shows a section of the amphitheater of the new Paris Sorbonne, containing 3,000 seats. *A* is the fresh-air inlet ; *C*, one of three propelling fans, each furnishing 20,000 cubic meters of air per hour. *D* is a furnace in which a portion of this air is warmed ; *F F*, cold-air shafts ; *g*, regulating valves ; *H H*, mixing chambers ; *I I*, hot pipes to counteract cold down-draught from the wall ; *J*, large central lantern for foul-air exit. The object is to provide for each person 20 cubic meters, or about 706 cubic feet, of fresh air per hour. This is less than half the amount that should be supplied.

The air inlets are in the floor under every seat and are covered with two perforated baffling plates of iron placed about an inch apart, and intended to allow the air to enter with a velocity of less than 1 foot per second. The outlets measure in all 45 meters square ; the final outlet shaft has an area of about 150 square feet. The apparatus was provided by Geneste and Herscher, and the idea is to heat the walls, which are hollow. About an hour before the public is admitted the temperature of the whole building is raised to over 140° F., but about 15 minutes before the entrance of the audience the heat is shut off and cool air is driven in by the fans. Thus the audience have warm walls and surfaces about them and breathe cool air in accordance with the ideas of M. Trélat.

* See effect of motion of air in an auditorium upon its acoustic qualities, by W. W. Jacques. Jour. Franklin Inst., CVI., 1878, p. 390.

With this amphitheater may be compared the New York Music Hall founded by Andrew Carnegie, a full description of which, with plans, is given in *The Engineering Record* of July 4, 1891, and February 6, 1892. The main concert hall has a seating capacity of 3,000, the recital hall beneath this seats 1,200. The fresh warmed air enters the music hall through numerous perforations in or near the ceiling,

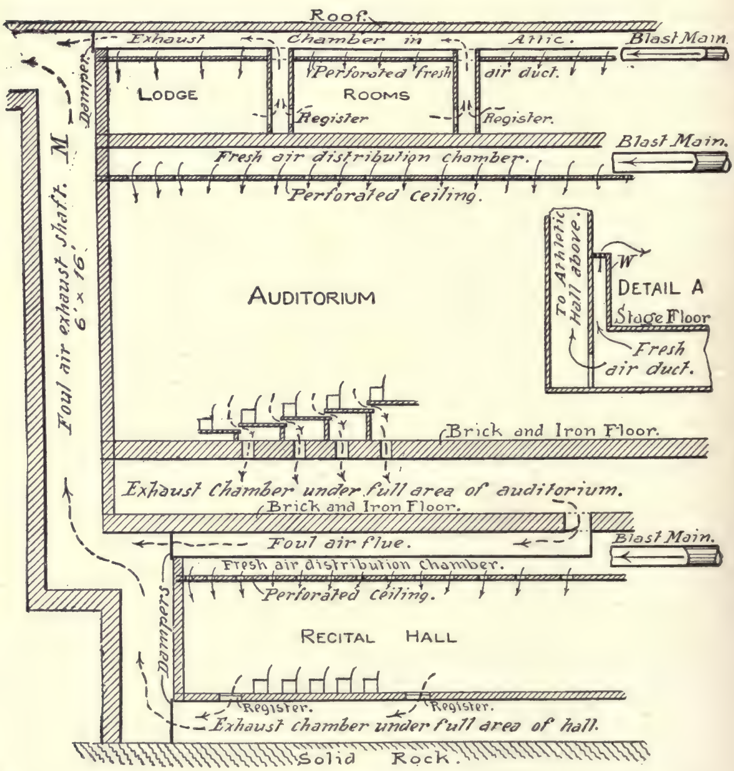


FIG. 129.

being forced in by two 7-foot Sturtevant blowers which draw it through heaters of 1¼-inch pipe containing 6,600 square feet of heating surface.

Figure 129 is a general vertical section of the main building, not to scale or accurate position, but intended as a diagram to show the distribution of fresh air and the withdrawal of foul air in the principal

rooms. Detail A shows the method of supplying extra heat and air to the stage through perforations in the horizontal top of the 6-foot wainscoting *W*, around the walls.

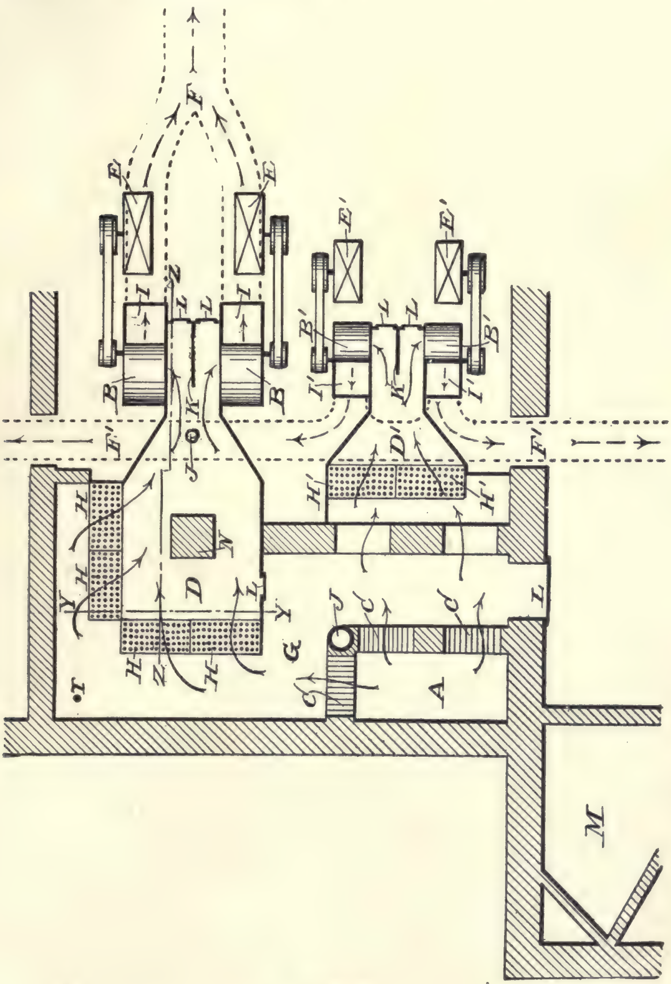


FIG. 130.

Figure 130 shows the heating, cooling and blowing plant. *A* is the fresh-air shaft from the roof, 6x12 feet, supplying the distributing

chamber *G*. In warm weather ice may be placed in the racks *C C* to cool the air. The blowers *B B* draw the air into the chambers *D D* through the steam radiators *H H'*. *E E* are the engines driving the blowers, and *F* is the main air duct having a cross-section of 30 square feet.

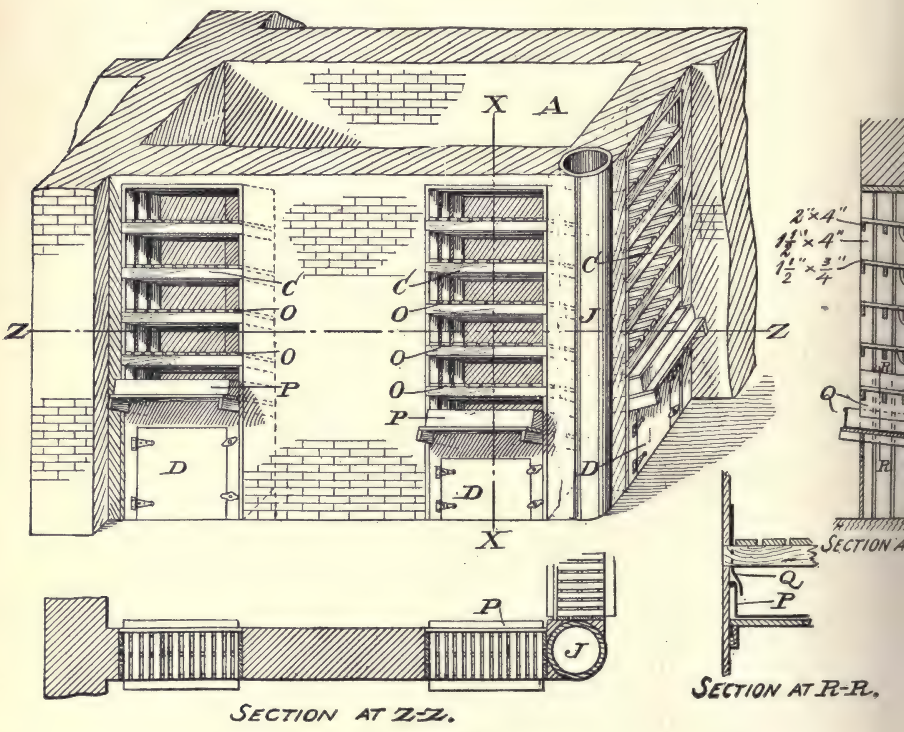


FIG. 131.

Figure 131 shows the bottom of the fresh-air shaft *A*, with its outlets. *O O* are the ice-racks; *P P*, iron drip-pans. *S S* are waste-pipes; *D D*, doors.

Figure 132 is a perspective view from *T*, Fig. 130, of the chamber *D*, two sides of which are composed of radiators *H H*. *U* is the steam supply and *V* the drip pipe.

Figure 133 is a section at *z z* Fig. 130 showing the inlet to the blower and the check valve *F*, which opens with the blast but closes against

back pressure. The air is drawn out from the hall by a separate fan system, being taken from or near the floor levels, and carried in a shaft to the roof where the exhaust fans are located. It will be seen that this

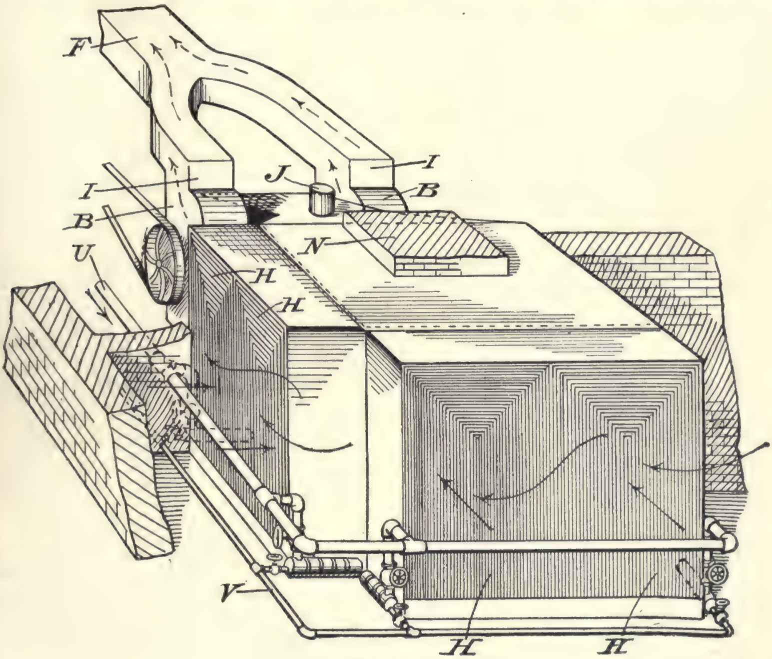


FIG. 132.

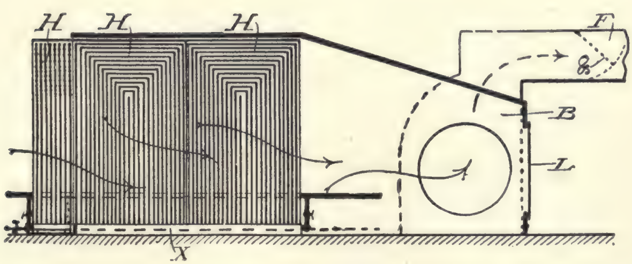


FIG. 133.

is a system of downward ventilation, the efficiency of which can only be maintained by a considerable expenditure for power.

Figure 134 is a plan of the basement of the Lenox Lyceum in New York City, which is described as follows in *The Engineering Record* of February 1, 1890:

The main portion of the building is circular in form, and is almost wholly taken up by the auditorium, which is 75 feet high and 135 feet in diameter, with a total seating capacity for 2,300 persons. The dining-room in the basement will seat 800 persons. Around this room

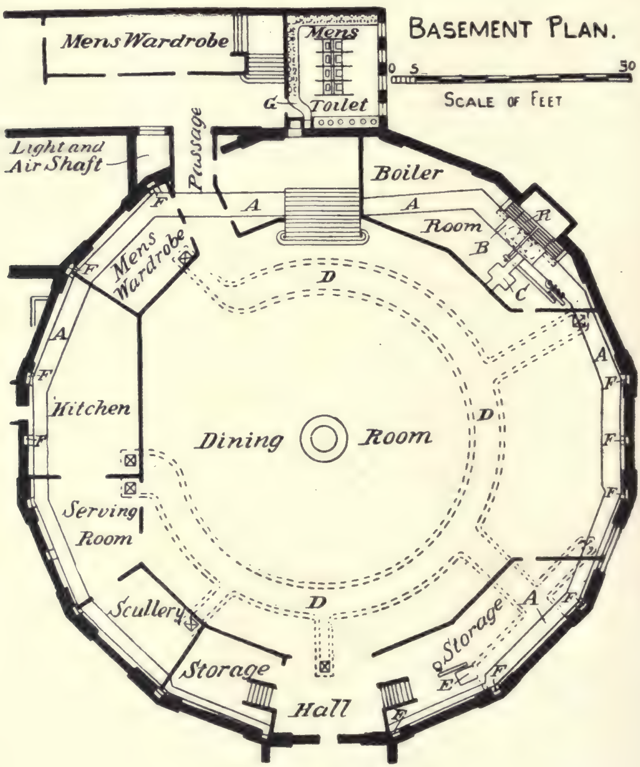


Fig. 134.

are arranged the overhead fresh warm air ducts *A A*, branching out right and left from an 8x4-foot Sturtevant blower *B*. Fresh air is taken in through a flue in the south wall, having a sectional area of 20 square feet, and is passed over a large steam radiator of special design, being finally delivered into the galvanized-iron distributing duct

The entire contents of the auditorium and dining-room amount to 900,000 cubic feet, and the blower is designed to effect a complete change of air every 15 minutes. Branch pipes run from the main hot-air duct, and are connected to a series of gratings placed near the floor of the auditorium. These are covered with perforated zinc plates through which the flow of fresh warm air is brought down to a velocity so low that there is no possibility of draught. Hot-air flues *F* also rise to the gallery floor.

The hot-air supply for the dining-room is taken from the same blower through the duct *C* issuing near the ceiling, but the air is heated to a much higher temperature than that entering the auditorium, and is delivered in proportionately smaller volume. The higher temperature is secured by interposing in the duct *C* a separate radiator as shown. This air supply is entirely discontinued when a proper temperature has once been secured in the room.

Regulation of the temperature is effected automatically by Johnson electric heat regulators, which control the steam supply to the radiators in the fresh-air flue according to the temperature of the auditorium and of the air entering it. One of the regulators also controls the large 10-foot ventilator in the roof of the auditorium, by which a uniform volume of fresh air is delivered, and a practically fixed temperature is maintained in the auditorium.

A thermostat, or electrical thermometer, is placed in the auditorium, another in the main air duct near the fan, each capable of making electrical connection with the electro-pneumatic valve, which shuts off the steam supply to the radiators when the auditorium becomes warm. The delivery of fresh air is maintained, although at a reduced temperature, and to prevent the air from falling below 72 degrees, no matter what temperature the air in the room may be, the thermostat in the main duct, at 72 degrees, permits just enough steam to enter the coils to raise the air to 75 degrees, when the steam is again turned off.

But should the temperature of the auditorium fall below 70 degrees, or the degree at which the thermostat is set, the auditorium thermostat would turn on steam regardless of the thermostat in duct, and so continue to control the steam supply until the temperature in the auditorium rises to the degree required.

Still another thermostat in the auditorium is set 4 degrees higher than the thermostat which controls the coils. When the atmosphere in auditorium is heated to the degree at which this thermostat is set the large 10-foot ventilator is opened, permitting the heated air to escape.

The volume of fresh air entering the building is capable of variation by increasing or diminishing the number of revolutions of the blower. Ordinarily the speed of the latter is 100 turns per minute, at which the capacity of the blower is about 40,000 cubic feet of air per minute.

For the purpose of ventilation a large brick duct *D D*, was built below the dining-room floor, encircling the room. Branches from this lead to register boxes in the floor at various points, and also in the kitchen, and the foul air is drawn into the duct and discharged into the open air by a 4x6-foot Sturtevant exhauster *E*, driven by a 10 horse-power vertical engine. This exhauster has a capacity of 15,000 cubic feet of air per minute. The movement of the air will always be from the main auditorium to the dining-room, thence to the kitchen, and finally into the exhaust duct. Odors from the kitchen or dining-room are thus prevented from rising to the main auditorium. Above the urinals in the toilet-room an exhaust duct *G*, of 3-square foot section is arranged, having small openings downward, as shown by dotted lines, and discharging into a flue leading to the roof. The ventilation there is effected by natural draught, which is sufficiently strong to create a flow of air into the toilet-room from the adjoining spaces on opening the door.

The apparatus is designed also to cool the building in warm weather. For this purpose a tank is arranged underneath the engine-room to hold cold water, which is forced through the radiator in the fresh-air flue by a small circulating pump.

CHAPTER XVI.

THEATERS. AIR IN MANCHESTER THEATERS. GRAND OPERA HOUSE IN VIENNA. OPERA HOUSE AT FRANKFORT-ON-THE-MAIN. METROPOLITAN OPERA HOUSE, NEW YORK. MADISON SQUARE THEATER. ACADEMY OF MUSIC, BALTIMORE. PUEBLO OPERA HOUSE. EMPIRE THEATER, PHILADELPHIA.

AS a rule, theaters have insufficient and unsatisfactory arrangements for ventilation. They almost invariably become overheated when the audience is large, while the stage is, as a rule, cold and exposed to draughts. The difficulties in the way of obtaining satisfactory results are much the same as those in large legislative halls, and are to be overcome by much the same methods.

The following tables showing the condition of the air in the principal theaters in Manchester, taken as types of well-arranged English theaters, are taken from a paper by W. H. Collins, in the Report of the British Association for the Advancement of Science, 1890, p. 773.

If we could have similar reports for some of our modern theaters, such as are described in this chapter, they would add greatly to the limited stock of reliable information on this subject.

Samples of air were taken at stated periods during the performances in the months of December, 1889, and January, 1890. Duplicate samples were analyzed in all cases, and samples of the air outside the theater were taken simultaneously for the purpose of comparison. The examination of the samples was confined to the estimation of (1) carbonic acid (by Pettenkofer's method); (2) organic matter (by Carnelley's method, and (3) micro-organisms (by Hesse's method, "Mittheilungen aus dem kaiserlichen Gesundheitsamte," ii., 1892).

The results are contained in the tables given on pages 380 and 381.

Of late years more attention has been paid to the ventilation of opera houses and theaters by architects, and some very good results have been obtained.

Probably no theater in the world excels the Grand Opera House in Vienna in the extent and completeness of the special arrangements for securing ventilation, and in no theater of the same size, and under similar climatic conditions, have better results been obtained.

The heating and ventilation of this building were arranged by Dr. Böhm, the medical director of the Hospital Rudolfsstiftung, in Vienna.

Tables Showing Condition of Air in Manchester Theaters.

A.—Comedy Theater, Manchester.

Place.	Time.	Temp. F.	CO_2 Per 10,000.	Organic Matter. Per Cent.	Bact. 1 c.c.	Molds Per c.c.	Total Micro-Organisms.
	P. M.	°					
Stalls	6.30	53	12.6	14.6	6	34	49
"	9.0	71	9.6	34.2	29	41	70
Pit	9.40	96	11.3	60.4	36	39	75
"	10.5	103	13.9	63.1	69	104	173
Gallery	8.5	90	12.1	49.0	34	20	54
"	9.5	116	12.6	56.3	45	45	90
Peter Street outside the theater.	6.30	36	5.1	16.6	25.3	63	89
	9.0	36	5.0	16.9	26.9	106	140
	9.40	37	5.1	16.6	40.6	64	116
	10.5	37	5.2	17.1	109	103	214
	8.5	36	5.2	26.9	26	41	73
	9.15	36	5.3	16.9	26	40	66

B.—Theater Royal, Manchester.

Place.	Time.	Temp. F.	CO_2 Per 10,000.	Organic Matter. Per Cent.	Bact. 1 c.c.	Molds Per c.c.	Total Micro-Organisms.
	P. M.	°					
Pit	7.45	69	12.6	69.5	60	60	120
"	8.15	100	14.1	70.0	65	69	134
Gallery	8.30	121	16.9	105.0	96	106	202
"	9.30	116	16.5	109.0	97	120	217
Circle	9.30	95	12.3	46.0	29	11	40
"	10.0	90	11.3	69.0	36	41	77
Peter Street outside the theater.	7.45	39	4.9	16.9	26	40	66
	8.15	39	4.9	17.4	31	36	67
	8.30	36	5.3	17.9	39	30	69
	9.30 9.30	33 33	5.6	26.9	45	60	105
	10.0	35	5.9	63.6	69	100	169

C.—PRINCES THEATER, MANCHESTER.

Place.	Time.	Temp. F.	CO_2 Per 10,000	Organic Matter, Per Cent.	Bact. 1 c.c.	Molds Per c.c.	Total Micro-Organisms.
	P. M.	°					
Pit	7.45	67	11.3	60.5	16	26	42
"	9.0	104	13.0	106.0	69	43	112
Circle	8.0	73	10.9	49.0	40	6	46
"	10.0	90	14.0	109.0	26	90	116
Gallery	7.45	94	14.6	116.0	60	40	100
"	10.0	116	17.3	206.0	143	51	194
Peter Street outside the theater.	7.45	39	5.6	16.5	29	6	35
	9.0	40	5.0	17.3	20	9	29
	8.0	37	4.9	17.9	25	41	66
	10.0	32	4.6	16.9	6	51	57
	7.45	39	5.1	40.3	15	11	26
	10.0	30	5.0	40.9	12	14	26

The plan and section of so much of the building as is necessary to show the ventilation of the audience hall are given in Figs. 135 and 136. The letters mark the same features in each figure and have the following meaning :

A.—Fresh-air chamber.
B C D E.—Heating chambers.
G.—Tubes for fresh cold air.
H.—Foul-air shaft.
S.—Fresh-air fan.
U.—Foul-air for aspirating fan.

The building measures 397x299 feet, and the theater itself will contain about 2,700 persons. The ventilation is produced and regulated by two fans, as will be seen on the plans—the lower one for propulsion, the upper for aspiration. This last is also aided by the heat produced by the great chandelier, which has 90 burners. The heating is effected by steam, and the air enters the hall at a temperature of from 63 to 65 degrees F., the points of entrance being at the floor and in the risers. Each gallery and compartment of the theater, including the stage, has an independent supply duct and independent means of heating, so that the amount of supply and the temperature can be regulated for that portion irrespective of the rest. The velocity of entrance of the air is between 1 and 2 feet per second. The lower fan is a helix, devised by Professor Heger, of the Polytechnic School of Vienna. It measures 11½ feet in diameter externally, and has a capacity of 3,531,658 cubic feet of air per hour, the ordinary figure being from 2,825,324 to 3,001,907 cubic feet, corresponding to 1,059 cubic feet per head per hour The aspirating fan, in the upper shaft, is a simple helix, and is of little use. Both fans are operated by an engine of 16 horse-

power. There are two fresh-air shafts of supply, each being 19½x13 feet. From these the air passes into a basement chamber, where in warm weather, sprays of cold water are made to play. From these it passes to the lower fan, the air duct from which is 48½ square feet in area. This duct passes below the center of the theater into a large space having the same extent as the main hall. The space is divided into

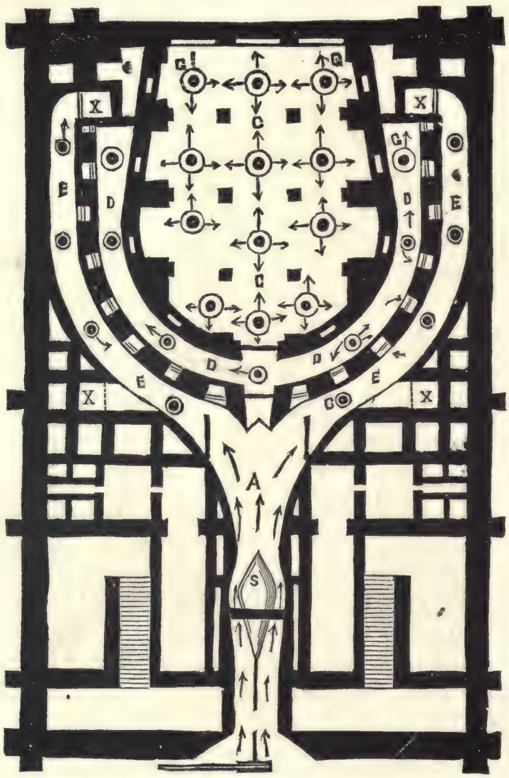


FIG. 135.

three stories. The lower story is divided into distinct chambers, corresponding to the orchestra chairs, dress circle, the galleries, etc. The second stage contains the heating coils, which are composed of 59,058 feet of tubing of 1-inch interior diameter, containing steam at a pressure of five atmospheres. The upper story is the mixing chamber. It will be seen by Fig. 136 that the fresh air may pass directly from the lower

to the upper floor, or mixing chamber, through tubes about 3 feet in diameter, without passing through the heating coils at all. These tubes are valved, and can be opened or closed to any extent. The foul air passes out through the shaft shown in Fig. 136, which shaft is 13½ feet in diameter. The floor surface occupied by spectators is 14,608 square feet, the capacity of the hall is 388,482 cubic feet, and the combined area of the fresh-air inlets into this hall is 807 square feet.

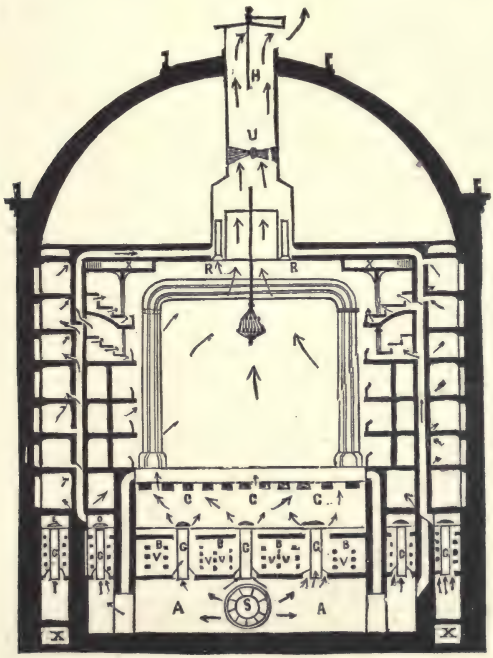


FIG. 136.

By means of electricity the temperature in different parts of the house can be observed in a central office of control, and here also are levers which control the valves which regulate the air supply, both hot and cold.

During an operatic performance, the superintendent of heating and ventilation is on duty in this office, and sees that all parts of the house receive their due supply of fresh air, and are kept at a proper temperature.

In connection with the heating and ventilating arrangements of the Vienna Opera House should be mentioned those of the new Opera House in Frankfort-on-the-Main, which are arranged upon essentially the same system, although with improvement as to details, more es-

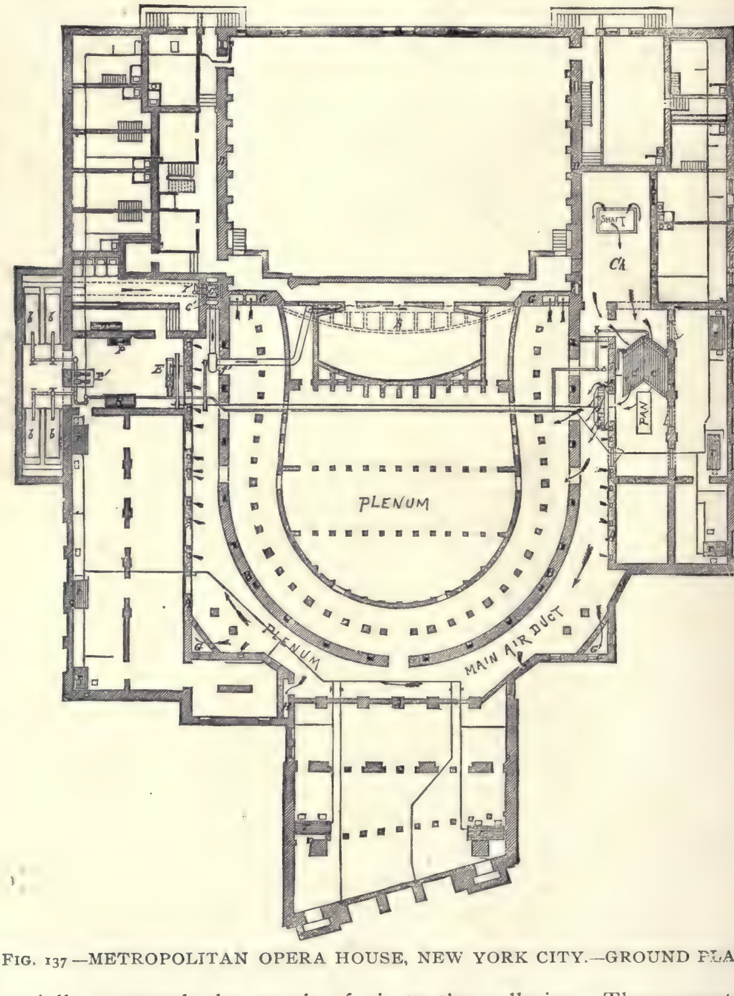


FIG. 137—METROPOLITAN OPERA HOUSE, NEW YORK CITY.—GROUND PLAN

pecially as regards the supply of air to the galleries. The apparatus in this building is designed to supply warmed and moistened air sufficient for 2,000 persons. The warming is effected by steam,

the boilers for this purpose being in the cellar of a building placed on the opposite side of the street and connected with the opera house by

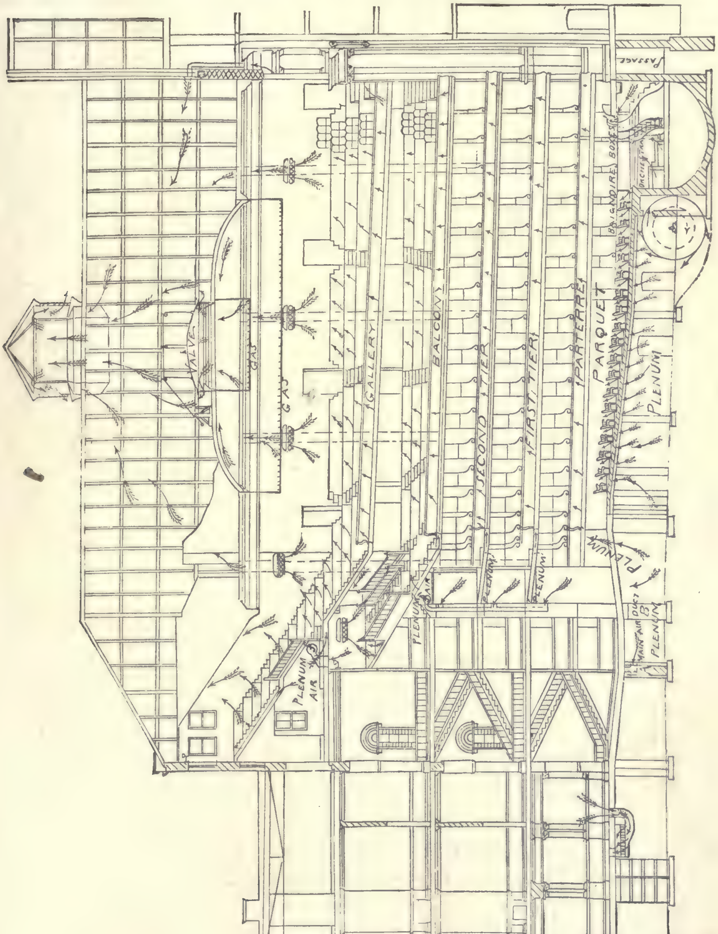


FIG. 138.—METROPOLITAN OPERA HOUSE, NEW YORK CITY. LONGITUDINAL SECTION.

means of a tunnel passing beneath the pavement. There are two of these boilers, each having about 540 square feet heating surface, and

supplying steam at from six to nine pounds pressure. The radiators in the heating chamber beneath the audience hall and stage are the usual pipe radiators, and furnish 10,800 square feet of radiating surface, two-fifths of which is devoted to the stage and adjoining rooms.

The fan for propelling the fresh-air supply is a helix, 9½ feet in diameter, of the same pattern as that used in the Vienna Opera House, and it furnishes in winter 2,800,000 cubic feet of air per hour, or 1,400 cubic feet per person, being an increase over the amount allowed in Vienna. The maximum capacity of the fan gives about 2,400 feet per head per hour, and this is intended to be the summer supply. Provision is made at the point of entrance of the fresh air into the building for cleansing, moistening and cooling it by drawing it through sprays of water.

The general results obtained by the apparatus are very good, and are especially well marked in hot weather, when a good audience can always be collected in this building, because of its coolness, freshness and comfort.

The Metropolitan Opera House, in New York City, recently burned, was another large building of this class in which excellent results were secured, so far as heating and ventilation are concerned. The apparatus in this case was devised by Mr. Frederic Tudor, and is described in *The Sanitary Engineer* of December 6 and 13, 1883.

The principle involved was "plenum ventilation," the object being to have a pressure within the building slightly in excess of that of the air without the walls, so as to insure an outward current through crevices of doors or windows or through accidental openings. To this end the shaft (at the right of the stage on the ground plan) 7′x10′6″ (73.5 square feet), was provided in connection with the fan, *f*. Air was taken in at a height of 75 feet from the ground, and 60 feet below the top of the boiler chimney, and as remote therefrom as possible. The air drawn down through the shaft entered a settling chamber, 48x20 feet, with a height of 10 feet, and thence it was drawn through the heating coils *C C*, or passed around through the swinging doors, as shown, to the fan. From the fan the general course of the air is through the main air duct, between the walls *A* and *B* in the basement in the direction of the arrows, but all the basement within the walls *A A* is subject to the same pressure. From the basement room immediately under the auditorium floor the air was admitted through many 4x4-inch openings made through the brick arches into the space between the arches and the floor. From this space the air for the occupants of the parquet chairs passed through the risers of the floor steps on which the chairs

were set. In these risers were openings continuous at their face, but of peculiar construction, and covered with No. 16 galvanized iron perforated with $\frac{1}{10}$-inch holes.

The air which supplied the boxes was carried from the main air

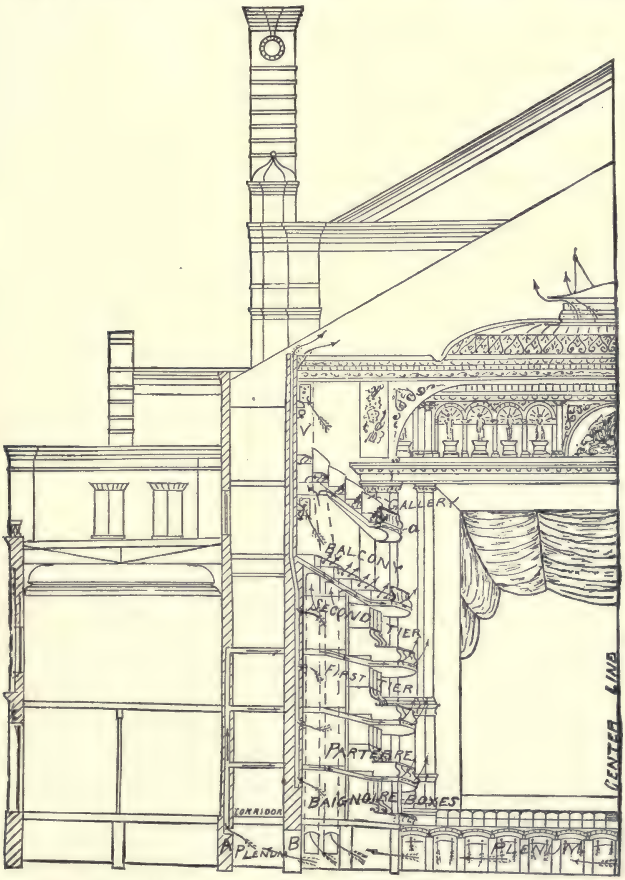


FIG. 139.—METROPOLITAN OPERA HOUSE, NEW YORK CITY.—TRANSVERSE SECTION.

duct in the flues in the wall A to the spaces between the floors and ceilings, as shown on transverse section, and discharged at the edges of the tiers at a a. Its course was then upward and backward, to the flues in the wall B, which had an exhausting power derived from the

heat of the gas-jets under the hoods in the balcony and family circle, and from the gas-light, when used, in the private parlor, immediately behind the chairs, a detail of which is shown in Fig. 139. The balcony and family circle received air through the large flues *G G* at the ends of the main air ducts in the proscenium wall and through the flues *G G* and *H* in the wall *A*.

"The air was discharged into the spaces shown, formed by the ceilings of the box parlors on the second tier and by the ceiling in the angle of the balcony at the walls. It was then distributed to the edge of the balcony and family circle at *a a* and through a 2x4-inch hole at the back of every chair in the risers of the galleries.

"The outlets for foul air were those already mentioned in the boxes, and shown in the wall *B* (ground plan), and those in the proscenium wall at the ends of the gallery and balcony.

"In the highest part of the gallery ceiling, in the rear, were five registers, under two of which there were clusters of gas brackets, the aggregate area being 20 square feet. In the balcony ceiling there were likewise *four* registers of 15 square feet, under each of which there was a cluster of gas brackets. The foul air from these was likewise carried to the wall *B* in galvanized ducts.

"In the center of the dome-shaped ceiling was the main controlling valve to the ventilation. It was circular, 16 feet in diameter, and admitted of adjustment by the raising and lowering of the bell-shaped disk by the winch shown in the longitudinal section.

"By the adjustment of this valve, the pressure within the house could be regulated and the condition of plenum maintained under varying conditions of the speed of the fan made necessary by climatic changes.

"All the foul-air outlets in front of the proscenium wall opened into the space between the ceiling and the roof, and reached the outside atmosphere through the louvered ventilator at the apex of the roof. This ventilator had openings equal to 108 square feet, with an inner shield to prevent the admission of snow or rain.

"The stage had separate ventilators at the roof and in the side walls, and was warmed by direct-radiation coils on the back wall. By this means a difference of pressure is kept between the house and the stage when the curtain is down; enough to belly the latter slightly toward the stage. The rising of the curtain then allows air to pass from the house to the stage ventilators.

"In the coil chamber, between the coils *C C* and the fan was placed an evaporating fan, to regulate the hygrometric state of the in-

coming air. The difference of temperature between a dry and wet bulb thermometer, in the main air duct, was maintained at from 14 to 16 degrees.

"To regulate the hygrometric state of air after it left the coils, the evaporating pan (marked *Pan*, on the ground plan), a detail of which is shown in Fig. 140, was devised. The pan proper was of iron, 4x12 feet, and 12 inches deep. Within the pan was a brass coil of 1-inch pipes, *a*. This coil had a steep incline, as shown in the section,

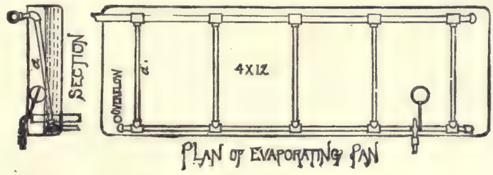


FIG. 140.

Fig. 141. The elbow of each inclined pipe was at the level of the top of the overflow pipe, but the other end rested on the bottom of the pan. By raising or lowering the water in the pan, more or less of the coil was submerged, and more or less moisture driven off into the air.

"Figure 141 is a detail of the manner of admitting air through the auditorium floor. The arches were of brick, and the whole space between them and the wooden floor was filled with warmed air, which entered through a baffle *a*, that ran the whole length of the steps.

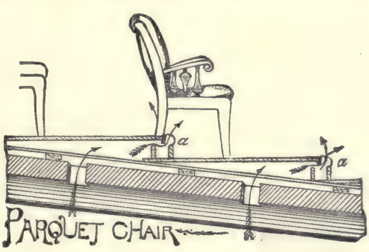


FIG. 141.

"Figure 142 is a section and plan of the private boxes, of which there were 120. The air was carried through the floors from the flues in the wall *A*, and delivered at the edges of the box balconies, as shown.

"Figure 143 represents the special ventilation of the footlights. At the edge of the stage at *S*, on the ground plan, was a system of flues connecting with the exhaust fan *F*.

"The section is through one of 11 short flues, 8x12 inches, which connected the space formed by the metal reflector and the metal edge of the stage, with a main or trunk flue, which in turn connects with the fan. This space, within which the three gas pipes for the different colored lights lie, was divided into as many sections as there were

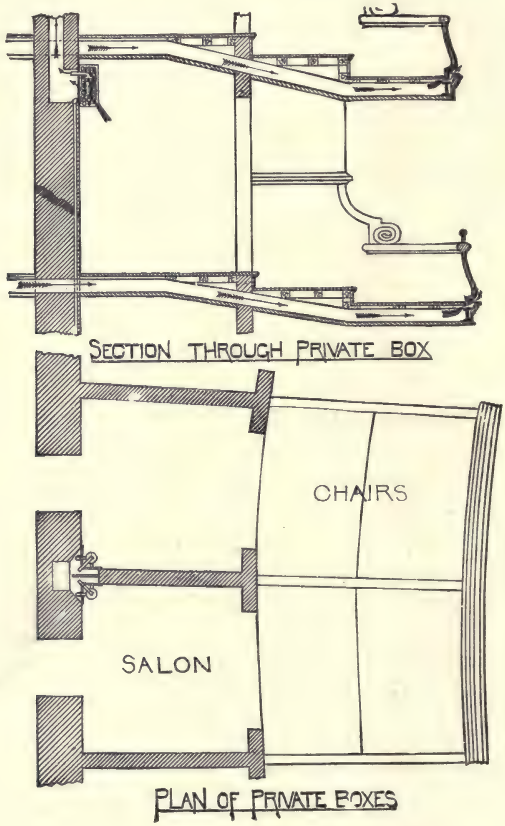


FIG. 142.

branch flues, and within each flue was a damper *d*. These dampers were set and fixed with the use of a water gauge, so as to give a difference of pressure in each flue of one-half inch water pressure, the object being to get an equal pressure of draught into all the openings at the edge of the reflectors, over the gas chimneys.

"The main fan was 12 feet 6 inches in diameter by 45 inches in the width of the blades, and delivered about 70,000 cubic feet of air per minute at 100 revolutions per minute."

Another theater in New York, in which special attention has been given to ventilation, is the Madison Square Theater, a good description of which, prepared by Mr. W. G. Elliott, was published in *The Sanitary Engineer* for October 15, 1880. From this description I take the following extract:

"From near the rear end of the gable a square wooden cupola rises to a height of about 20 feet above the roof. Each side of this is provided with two sliding shutters operated by ropes from below. These openings face the cardinal points of the compass and are used in pairs; thus, if the wind is southwest, the shutters at the south and

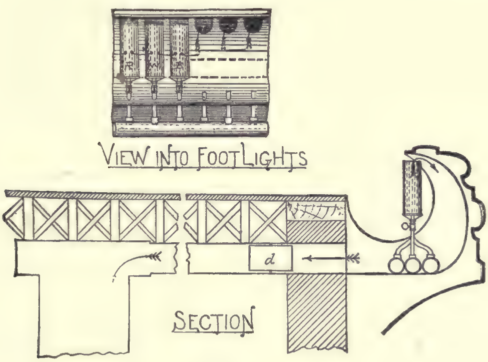


FIG. 143.

west are opened while the others remain closed. The shaft into which these open is square, 6 feet in section, and extends downward behind the scenes to the cellar.

"This inlet shaft, as well as many of the larger ducts, is constructed of smoothed pine boards, sheathed in places with paper, and having few bends.

"Suspended in it, point downward, is a conical-shaped cheesecloth bag, about 40 feet deep, through which the incoming air is filtered. A chamber at the bottom of the inlet is provided with a number of shelves inclined at an angle of about 45 degrees, upon which, in summer, ice is placed to chill the air. From this point, the main duct, diminished to a diameter of 4 feet, connects at the axis with a Sturtevant fan, 8 feet in diameter, with blades 3 feet by 18

inches, and making 150 revolutions per minute. The periphery of this wheel, moving at the rate of about two-thirds of a mile per minute, forces the air at a high velocity into the delivery duct, 5x3 feet, in which is placed another mass of ice. Four tons are used every night, two in the delivery and two in the inlet duct.

"The delivery duct is of brick, and is branched into six sheet-iron pipes, each 2 feet in diameter. Two of these are again subdivided in two, and open into four brick chambers, 4 feet square. Three steam radiators are placed in each chamber to supply heat in winter.

"The auditorium is divided into four sections of 90 seats each, and every individual seat is supplied from the chambers by 4-inch tin pipes, 90 of which are connected with each chamber.

"Two of the 2-feet flues from the main brick delivery duct have not yet been accounted for. Each of them is subdivided into three smaller sheet-iron flues, one set passing up the side wall on the right and the other on the left of the house, and opening into the auditorium through several 4x10-inch orifices just beneath the first balcony, 10 feet above the floor, and also through a number of 2-inch openings in the lower edge of the balcony, and also across the entire front of the stage.

"Through the former openings in summer the cooled air is poured into the house to reduce the temperature and to furnish a supply for respiration.

"The dome chandelier, together with each wall bracket, are encased in glass, and pass the products of combustion into separate flues connected with the exhaust fan. The proscenium boxes and the elevated orchestra chamber have their separate inlets and outlets, while the galleries are as well supplied as the parquet.

"Another Sturtevant blower, 8 feet in diameter, located upon the roof near the middle of the building, is employed to exhaust the foul air.

"A wooden flue, 4x5 feet, descends from this at a sharp incline to the floor of the attic, there dividing at right angles into two smaller ducts 3 feet square. These are again subdivided in two, 24 inches square. Two of them withdraw foul air through six 6-inch pipes in the ceiling under both sides of the first balcony.

"The two others pass down to the lobby, opening into two 20x24-inch registers in the wall, and located near the floor on each side of the main entrance.

"An additional register, 5 feet in diameter, is placed in the ceiling at the rear of the upper balcony, and connected by means of a large flue with the main exhaust duct."

Another older building of this class which is worthy of note in this connection is the Academy of Music, in Baltimore. In this building the special object of the architects seems to have been to make the method of ventilation serve also to improve the acoustic effects, or, at all events, not to interfere with them. To this end it is desirable that the sound of the actor's voice shall, as far as possible, go with the main current of air rather than across or against it. For this purpose they bring the supply of air for the audience mainly from the stage, warming it when necessary by means of ordinary steam coils. Before the audience assembles the hall is warmed by hot air admitted through two openings in the parquet, which openings are usually closed before the performance commences. The exit of foul air is intended to be by a large shaft from the center of the ceiling, the opening of which is controlled by a valve. To secure distribution of the air, large exhaust flues are placed in the walls, opening below in the rear of the galleries and communicating above with the exhaust shaft above referred to. A sketch of the arrangement is given by Mr. Neilson, one of the architects of the building, in the second biennial report of the State Board of Health of Maryland, printed in 1878.

The acoustic properties of this theater are excellent, and the supply of air to the galleries is fairly good. The only force available for securing change of air for the seats on the lower floor is practically the heat furnished by the audience themselves, the supply of air being insufficient, and the great mass of the fresh incoming air curving upward as it enters from the stage. An objection to this direction of the main current is, that in case of fire the direction of the draught would be from the stage, with its mass of highly combustible material, toward the audience, so that the mass of smoke and flame would be whirled directly among the people.

The heating and ventilation of the Pueblo Opera House, at Pueblo, Col., are described and illustrated in *The Engineering Record* of May 23 and May 30, 1891, from which the following summary is taken:

Figure 144 is a ground floor plan of the building.

Figure 145 is a plan of the second floor, the third and fourth floors being substantially the same.

Figure 146 is a section of the stage and auditorium.

The main fresh-air duct *A*, from the propelling fan, is 54 inches in diameter, and is made of galvanized iron. Its branches carry air to the registers *F G H*. *O O* are direct radiators, and *R R* are openings into the foul-air shaft *Z*.

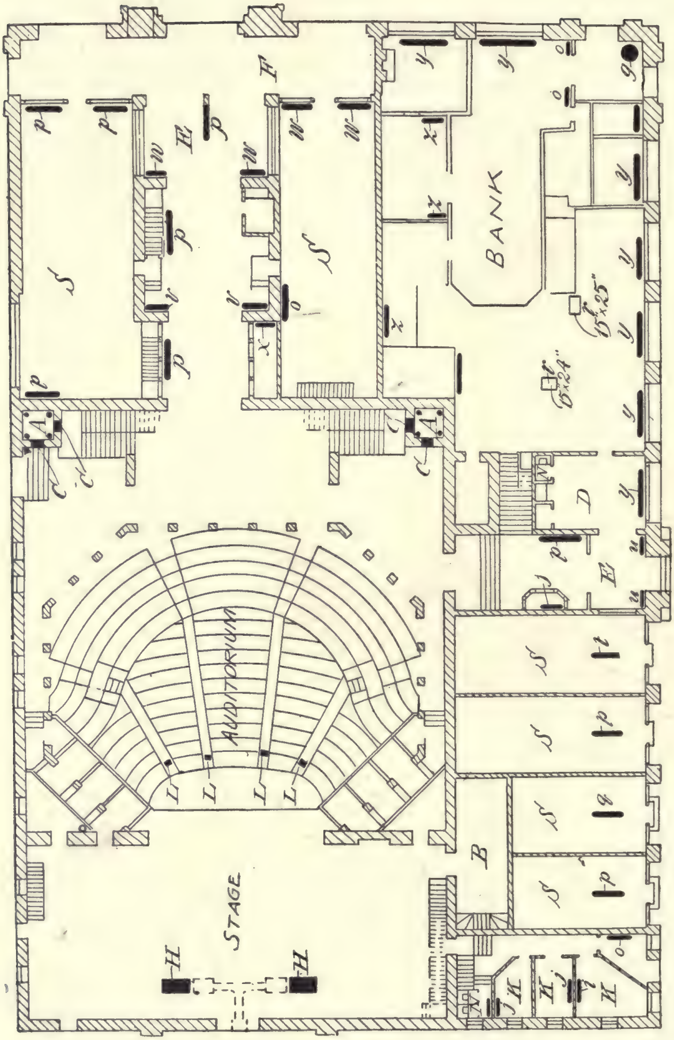


FIG. 144.

B.—Property room.
D.—Office.
E.—Vestibule.
F.—Lobby.
K.—Dressing room.
N.—Toilet room.
S.—Stores.
A.—Ventilating shaft.
H H.—Registers, 3x4 feet.
L L.—Registers from hot-air flues.
C C.—Openings into foul-air flues.
g h i, etc.—Direct radiators.

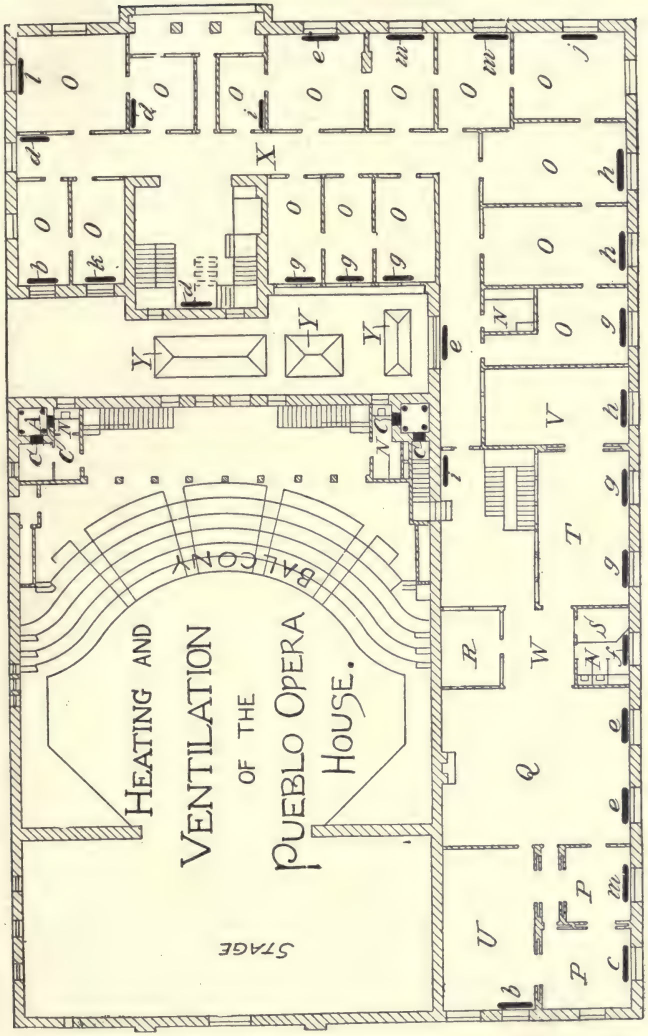


FIG. 145.

O.—Offices.
P P U.—Card rooms.
Q.—Billiard room.
Y.—Skylights from first-floor roof.
The small letters indicate direct radiators.

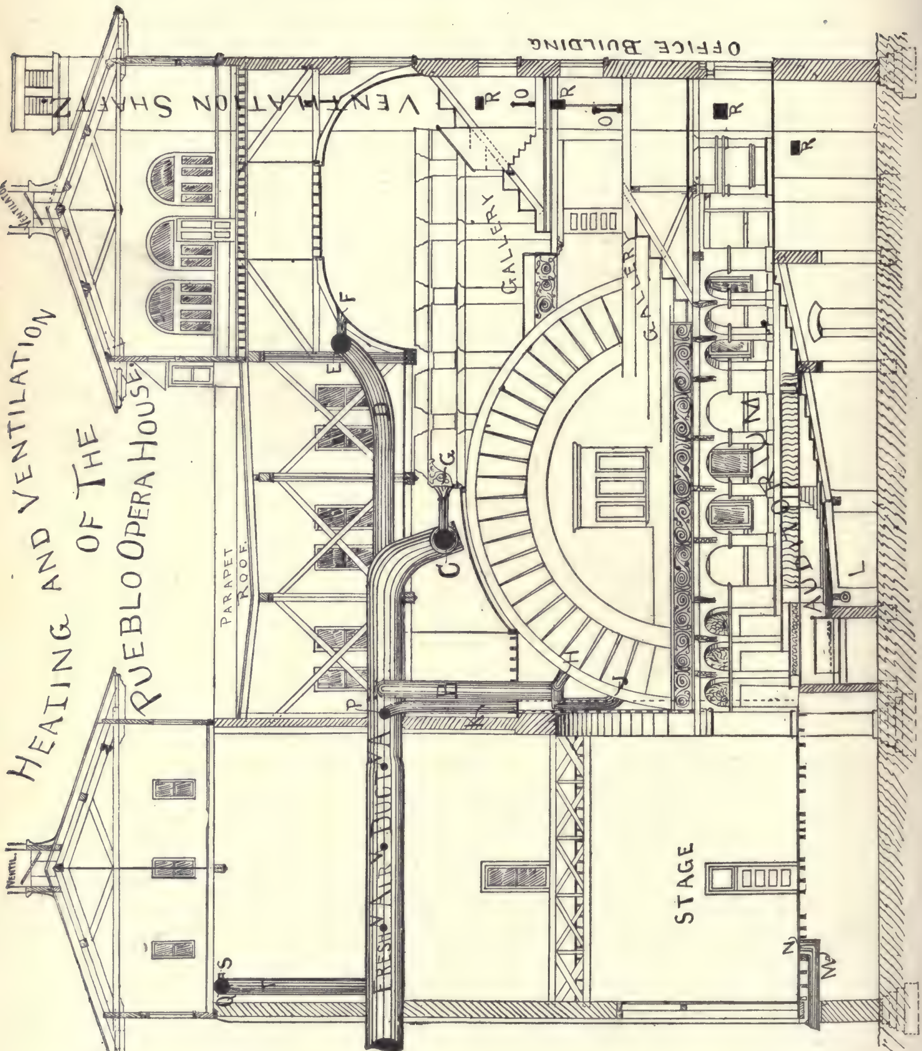

HEATING AND VENTILATION OF THE PUEBLO OPERA HOUSE
OFFICE BUILDING
VENTILATION SHAFTS
GALLERY
GALLERY
PARAPET ROOF
AUDITORIUM
STAGE
FRESH AIR DUCT

FIG. 146.

Figure 147 is a diagram plan of the air ducts.

Figure 148 is a plan of the fan chamber *Y* and coil room *X* in the second story of the boiler house. Figure 149 is an elevation at *Z Z*, Fig. 148. *B* is a 7-foot Sturtevant fan driven by the engine *E*, and discharging blast through the 54-inch conduit *A*.

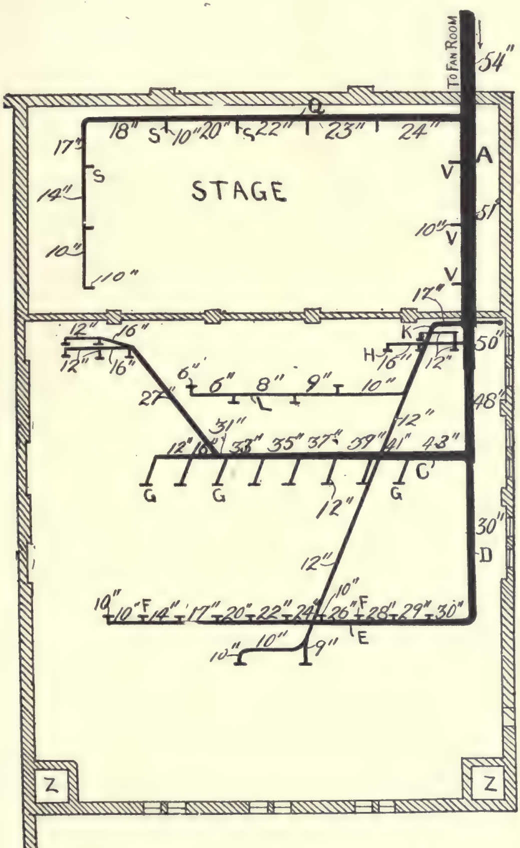


FIG. 147.

At *C* are the 12 heater coils, each eight pipes high, eight pipes wide, and 7 feet 6 inches long, supported on a pipe frame *L*. *W W*, etc., are counterweights balancing valve door *N*, which is operated by cord *H* from the engine room. Door *N* does not quite cover the whole opening in the partition *P*. When fully raised, as here shown, a lower

space *O* is left, through which the fan draws air, which has entered at *M*, and passing through the coils *C* has been slightly tempered and is delivered, comparatively cool, in duct *A*. If the door *N* is dropped to the floor the inlet is closed at *O*, and another one is opened at *Q*, from which the hottest air in chamber *X* is admitted to *Y*. Interme

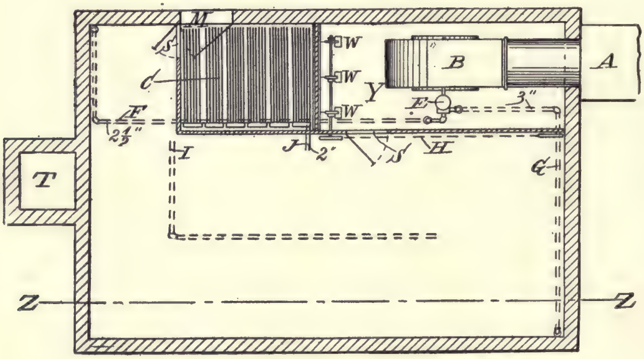


FIG. 148.

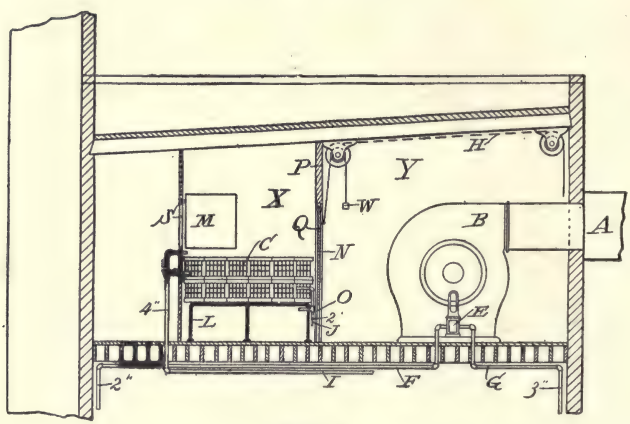


FIG. 149.

diate positions of door *N* enable the introduction of hot and tempered air in any desired proportions. *S S* are entrance doors to the chambers; *T* is the smoke-stack; *F* and *G* are steam and exhaust pipes to engine *E*; *I* is a steam pipe to radiator coils.

The heating and ventilating system was designed and installed by the L. H. Prentice Company, of Chicago, Ill. Adler & Sullivan, of Chicago, were the architects.

Figures 150 and 151 show in a floor plan and section the arrangements for heating and ventilation of the Empire Theater in Philadel-

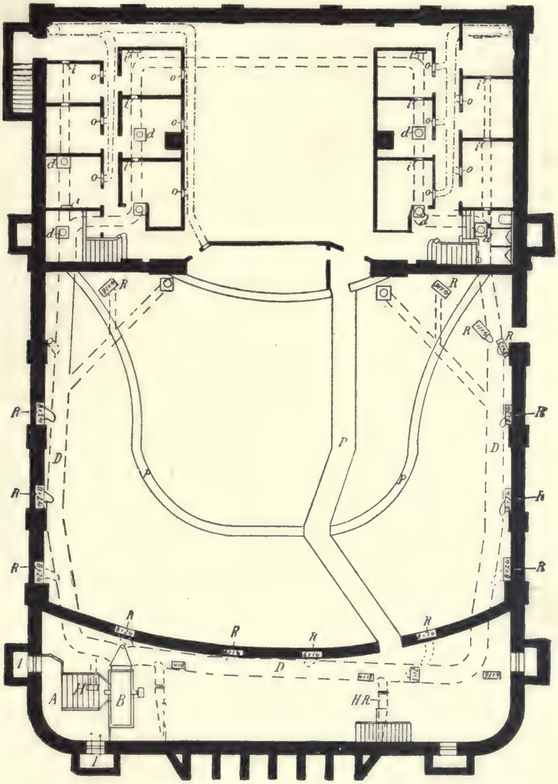


FIG. 150.—EMPIRE THEATER.—FLOOR PLAN.

A.—Fresh-air chamber.
B.—Blower.
H.—Heating coils.
I I.—Fresh-air inlet.
D.—Delivery ducts for fresh air.
R.—Delivery registers.
H R.—Hall registers.
P P P.—Passageway beneath auditorium.
i i i and *c c.*—Air inlets to dressing rooms.
o o o and *c c.*—Air outlets from dressing rooms.
d d d.—Dampers.

phia, as provided by the Philadelphia Steam Engineering Company. The total space in the building is 546,223 cubic feet, of which 277,375 are in the auditorium and 211,370 in the stages.

It is a hot-blast system, the fan being 7 feet in diameter, with an inlet 45 inches in diameter and rotating 250 times per minute. The heating coil contains 6,000 feet of 1-inch pipe arranged in eight independent sections.

The velocity in the main duct is intended to be 20 feet per second, and in the side wall flues 10 feet per second. The area of the flues for the auditorium is 19.75 square feet, and the registers have two and a half times the area of the flues. There are 20 of these placed 8 feet above the floor, and the air is supposed to pass through them with a velocity of 10 feet per second, which would give a quantity sufficient to renew the air in the room once in 15 minutes.

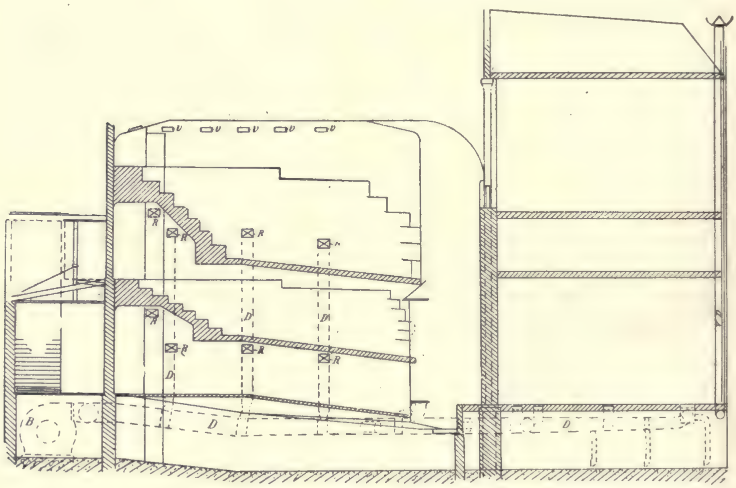


FIG. 151.—EMPIRE THEATER.—VERTICAL SECTION.

B.—Blower.
D.—Delivery ducts.
R.—Delivery registers.
V.—Outlets for air.
V S.—Ventilating duct for dressing rooms.

The area of the ducts for the stage is 8.75 square feet. The area of stage registers about 20 square feet. These registers are in the floor.

The outlet is from the ceiling of the auditorium through 16 openings, each 18x24 inches, into the loft which is surmounted by a large louvered shaft opening to the outer air. The dressing rooms, smoking room, etc., have separate ventilation.

The Royal Theater, of Copenhagen, built in 1872–74, seats about 1,750 persons, is heated by steam, and is ventilated by upward currents,

the air being brought in below the seats and taken out above. The supply of air is arranged for 546 cubic feet per second.

The central heating chamber contains two heating coils which may be used separately or together; one has 1,028 and the other 2,056 square feet of radiating surface. The air is introduced into the hall with a velocity of 1 foot per second. Above the central heating chamber is a mixing chamber into which cool air may be brought from without to keep the temperature of the mixture at 66° F., this being obtained by an automatic electric regulating apparatus. The stage is warmed by direct radiators.

In the Lessing Theater, at Berlin, the air to the auditorium is delivered beneath the seats, and 1,410 cubic feet per person per hour are allowed, entering at a velocity of 1.3 feet per second.

In the new theater at Prague 1,620 cubic feet of air are furnished per person per hour, and both a propelling and an exhaust fan are used.

In the Geneva theater, which is intended for 1,300 spectators, the air is drawn through the heating chambers and forced by fans into the auditorium through about 400 short vertical flues provided with sliding dampers and covered with perforated sheets of metal at their outlets which are beneath the seats. Other flues convey a portion of the air to the hollow floor of the first tier of boxes from which it escapes into the auditorium at a height of about 8 feet. The supply of air furnished by the fans to the auditorium and corridors is about 800,000 cubic feet per hour. The temperature of the upper gallery is about 5° F. higher than that of the pit. Exhaust fans draw the air through openings near the floors of the pit and of the first and second galleries. The general result is reported to be good.

The theater at Nice is ventilated in much the same manner, the allowance of air per head being said to be about 316 cubic feet per hour in winter, and 421 cubic feet in summer. Either the air supply must be much greater than this or the air must become very foul when the theater is crowded.

CHAPTER XVII.

CHURCHES.

AS a rule churches are like theaters in having insufficient and unsatisfactory arrangements for ventilation. There are, however, a few exceptions, and one of these is the Fifth Avenue Presbyterian Church, of New York City, commonly known as Dr. Hall's Church, which has been specially commended for its ventilation by competent judges, and, among others, by Captain Galton, who speaks of it as the best ventilated church he has seen.

I am indebted to the architect, Mr. Carl Pfeiffer, of New York, for the data and drawings, Figs. 152, 153, used in the following description:

This church covers an area of 100x200 feet, and the auditorium is 100 feet deep on the main floor, 136 feet deep on the gallery, 85 feet wide, with a ceiling 60 feet high, and is intended to furnish comfortable seats for 2,000 persons. At the northwest corner of the building is a tower 100 feet high and 16 feet square, which serves as a fresh-air shaft, down which the air is drawn by a fan at the base of the tower. The entire basement of the church is a fresh-air chamber, on the ceiling of which is a network of steam-heating pipes, 2 inches in diameter, amounting altogether to 9,000 feet in length. There is also an auxiliary coil in the air chamber adjoining the fan, containing 4,410 feet of 1-inch pipe, which is divided into four separate steam coils, each of which can be used independently. This auxiliary coil is in itself nearly, or quite, sufficient to furnish all the heat required under ordinary circumstances. But the pipes beneath the floor have been found very useful in warming the floor of the pews. The basement extends under the entire building, and is about 9 feet in height. It is not ceiled or plastered. The warm air forced by the fan into this basement air chamber, passes into the body of the church through openings in the risers of the stationary foot benches of every pew, these openings being controlled by slats, or registers, in such a way that the occupant of each pew can regulate the inflow of air at his

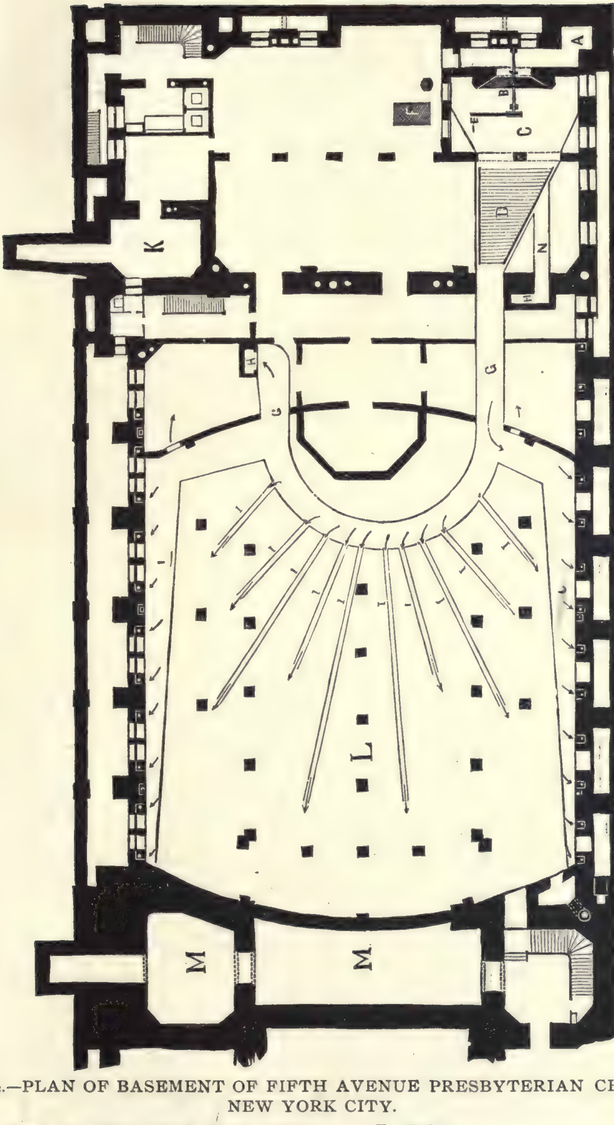


FIG. 152.—PLAN OF BASEMENT OF FIFTH AVENUE PRESBYTERIAN CHURCH, NEW YORK CITY.

A.—Fresh-air supply shaft from tower. Entrance for air 75 feet above ground.
B.—Fan.
C.—Air chamber.
D.—Heating coil, 4,410 feet of 1-inch pipe.
E.—Belt.
F.—Engine.
G.—Air duct.
L.—Air chamber for auditorium.
M.—Coal.

pleasure. The air also escapes into the aisles through openings in the ends of the pews.

Steam is usually turned into the pipes underneath the floor about 24 hours before the service in winter, and is turned off when the audience begins to enter, when the fan is put in motion. The forcing in of fresh air by the fan is continued between the interval of the morning and afternoon services, thus thoroughly flushing out the church. In warm weather the air is cooled by the spray of water from a perforated pipe at the bottom of the fresh-air shaft, and by the use of ice the temperature of the incoming air has been lowered as much as 6 degrees.

The fan is similar to that used in the Capitol at Washington, is 7 feet in diameter of disk, 8.5 inches wide at the tips of the blades, 5 feet in diameter at the mouth, 15 inches width of blades at the mouth, having three-eighths of an inch clearance between the edges of the blades and the wall or fan side, with an area of 19 square feet at the mouth and 15 square feet at the periphery. The area of the duct or passage leading from the chamber is 20¼ square feet.

The results of some experiments made upon the operation of this fan by Messrs. Skeel and Nason will be found in the *Journal of the Franklin Institute* for August, 1876, page 97. With a velocity of 66 revolutions of the fan per minute, the velocity of the air in the delivery duct was found to be 484 feet per minute, amounting to 9,900 cubic feet per minute. With the fan running at 110 revolutions per minute, the number of cubic feet delivered was 15,370. The authors make the following comment. Referring to experiment No. 1, when 9,900 cubic feet of air was supplied, they state that "at the end of the service of one and a half hours, with 1,400 people in the church, the proportion of carbonic acid in the air was found to be 12½ to 10,000."

An experiment made on the 4th of June, 1876, with the external temperature at 84 degrees, showed that with the delivery of 631,000 cubic feet of air, being 465 cubic feet of air per man per hour, the speed of the air through the registers was near the center of the church from 80 to 135 feet per minute. The temperature of the air in the air shaft was 77. When the water spray was turned on the temperature of the air entering the church was 73, the temperature of water itself being 69.

Complaints have been made at times by some of the audience of unpleasant draughts, and to prevent these there is a tendency to close the registers in the pews. When this is done in a part of the pews, the effect is to increase the velocity of the current through the remaining openings, and thus to induce the closure of these by the persons exposed

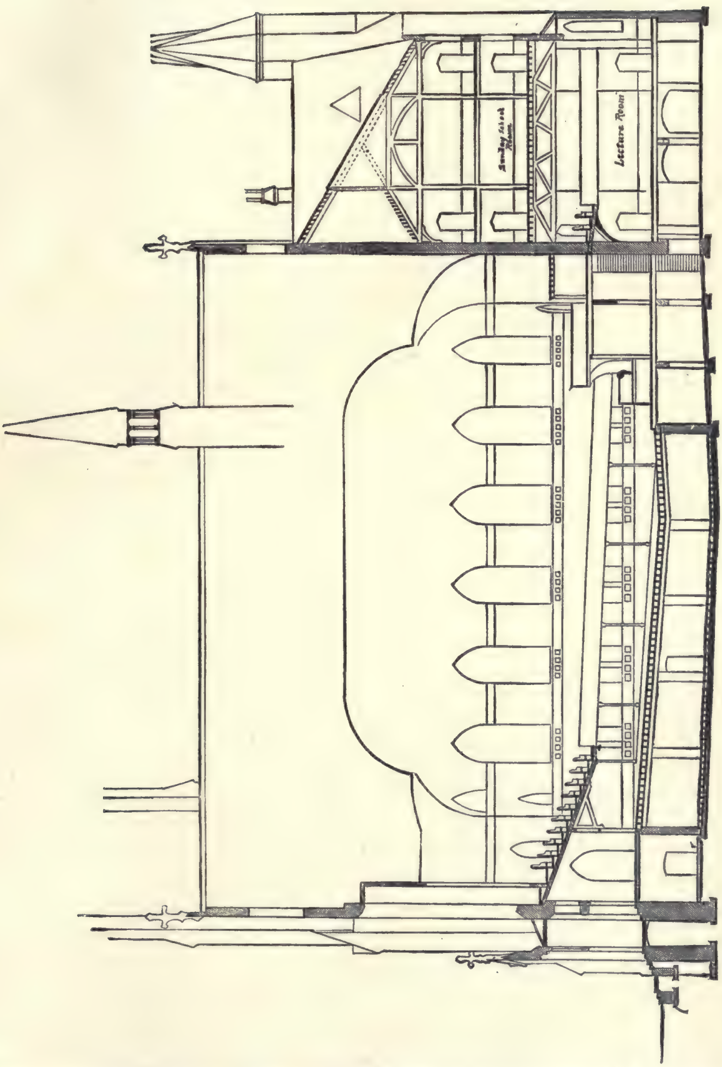


FIG. 153.—LONGITUDINAL VIEW—FIFTH AVENUE PRESBYTERIAN CHURCH.

to such currents. It is therefore impossible, when the church is full, to supply the amount of fresh air requisite to keep the proportion of carbonic acid down to 8 parts in 10,000, which is, I think, a fair standard for a building of this kind. To effect this, it would be requisite to increase the area of fresh-air openings in the floor, and probably a good way of doing this, without producing unpleasant draughts about the feet and ankles of the occupants, would be to have the partitions between the pews made hollow and used as air ducts, delivering the fresh air directly upward. This would increase the amount of air supply, and at the same time diminish the velocity of the currents through the lower openings to such an extent as to remove the desire to close them on the part of the pew holders.

As it is, however, this church is a vast improvement on the great majority of such structures, in which, as a rule, there are no special arrangements for the distribution of fresh air through the audience, and the effects of the steady increase of impurity in the air are usually distinctly perceptible in the audience during the last half hour of the service.

I am indebted to Mr. S. A. Jellett, of the Steam Engineering Company, Philadelphia, Pa., for the following description of the new Hebrew Temple, North Broad Street, Philadelphia:

The main auditorium of the new Hebrew Temple, Keneseth-Israel, a plan of which is given in Fig. 154, is ventilated by means of a fan located at the point *E*. The air supply is obtained through the wall openings *i i*. The fan is 120 inches high, 39 inches wide and 84 inches in diameter, with an inlet of 42 inches diameter and an outlet of 38x38 inches. At the outlet begin the main delivery ducts *A A*, which are 40 inches in diameter at this point and gradually decrease to 24 inches diameter, giving off at regular intervals branches for supplying air to the registers at the floor and gallery level of the auditorium. These branches are given off at an angle of 45 degrees and near the wall divide into two smaller branches, one of which directs the air over a steam radiator *R R R*, and thence through the registers on the floor of the room; the other passes directly up to the gallery level without being heated, the idea being to heat the air only at its lowest level. The aggregate transverse area of these delivery ducts is 29⅓ square feet which, with a velocity of 687 feet per minute, insures a delivery of 1,209,000 cubic feet of fresh air per hour.

For exhausting the air from the auditorium and to assist in holding the warm air at the floor of the building, there are 12 ventilating flues, dotted lines *B B*, and branches, eight of them coming up

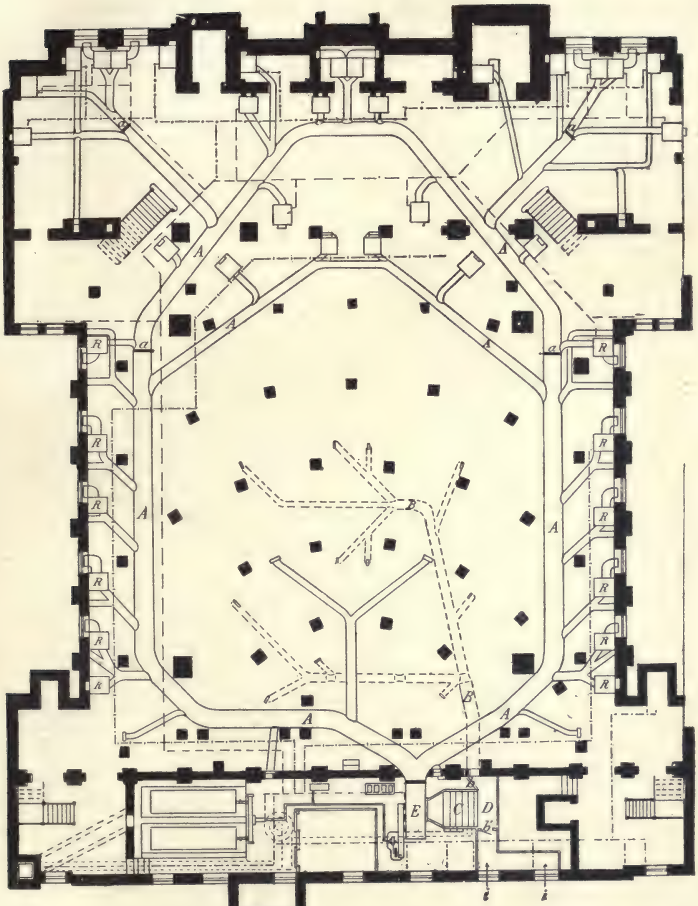


FIG. 154.—HEBREW TEMPLE, KENESETH-ISRAEL, BROAD STREET, ABOVE COLUMBIA AVENUE, PHILADELPHIA, PA.

i i.—Fresh-air inlets.
b'.—Dampers for controlling fresh air to blower.
b.—Dampers for controlling air from auditorium and blower.
C.—Heating coils.
E.—Blower.
D.—Air chamber.
A A, *etc.*—Delivery ducts.
R.—Radiators.
B.—Ducts for aspirating air from auditorium.

in the end of the pews in the aisles, and the other four coming up against the front of the pews facing the main platform. These 12 flues are each 4x15 inches in size, and drop down to the basement, where they connect with a series of galvanized-iron ducts leading to the air chamber back of the heating coils (*b* on plan). They have a gradual fall from the farthest connected point to the fans. The main duct, where it enters the air chamber, is controlled by a sliding damper which works on the wall inside the air chamber.

The point aimed at in this arrangement is to draw the upper layers of warm air down through these exhaust ducts, and in this way warm the center of the building before the congregation has assembled; in other words, to counteract the aspirating force of the dome over the auditorium. At the side of the fan, point *c* on drawing, is the heating chamber for the air that is to be propelled by the fan through the delivery ducts *A A*. The heater consists of six sections, containing approximately 4,500 feet of 1-inch standard wrought-iron pipe. Four of these sections are supplied with live steam at low pressure, and the other two with exhaust steam from the fan engine. Each section is controlled by separate valves.

The air capacity of the auditorium is 403,000 cubic feet. The glass surface is estimated at 2,126 square feet, the exposed roof and dome at 4,500 square feet, and the exposed wall at 5,580 square feet. The heating surface consists of 14 benches of indirect radiators, containing 1,360 square feet of heating surface, and a fan coil containing 3,600 feet of 1-inch pipe. In the heating coil, used as a fan chamber, it is assumed that 1 foot of 1-inch pipe is equal to 1 square foot of heating surface based on ordinary heating; that is to say, 1 foot of pipe will condense as much steam with the fan drawing air over it as 3 feet of pipe under ordinary conditions. This would represent, therefore, a total heating surface of 4,960 square feet for the auditorium.

The Baptist Church of Englewood, Ill., furnishes a good illustration of the method of heating by the hot-blast system and of employing an exhaust fan as an auxiliary in producing ventilation. The fresh air is delivered mainly through floor registers around the periphery of the church and the exhaust is also taken through floor registers into a large room in the basement from which it is discharged by a fan. The plans and description of the apparatus are given in *The Engineering Record* of May 9, 1891, and it is stated that the system is designed to change the air in the building once in every 10 minutes. It would be interesting to know what its effects are in ordinary use as shown by air analyses and by measurements of the velocities in the ducts.

As a curiosity in the way of radiating surface formulæ for a church, I give the following from the *Civil Engineering and Architectural Journal*, 1855, Vol. 18, page 107: "To the number of cubic feet in the church, divided by 300, add the surface of walls and roof divided by 120, the area of glass divided by 5, the superficial surface of doors and windows divided by 20, and the number of cubic feet of air withdrawn in ventilation divided by 6, the sum is the number of square feet of hot water radiating surface required."

To secure thoroughly satisfactory ventilation of a church at all times 2,400 cubic feet of air per head per hour are needed, but 1,500 cubic feet per head per hour will give good results under ordinary circumstances. Probably there are not half a dozen churches in the United States in which the last-named allowance is furnished during cold weather for the full seating capacity of the room, although it may be given for the number of persons actually present.

CHAPTER XVIII.

SCHOOLS.

OF all classes of municipal buildings in the United States, public or private, there are probably none which have, until recently, been in such an unsatisfactory condition, as regards their ventilation, as the public schools. In our large cities they still are, as a rule, overcrowded and insufficiently supplied with air, and for these and other reasons which I need not here specify, they are probably the cause of a vast amount of ill health and premature death, although these results are usually not so direct and immediate that they can be clearly traced. Every intelligent teacher knows that the dullness and listlessness in some pupils, and the irritability and peevishness in others, which are so manifest toward the close of the afternoon session, are closely connected with the gradual accumulation of foul air which has been going on through the day. If, after a brisk walk in the open air, you enter one of our city school rooms about 3 P. M., you will in most cases, find an odor which is far from being agreeable, and which, under such circumstances, is the characteristic sign of insufficient ventilation.

Taking a comparatively recent work on school architecture, which is very instructive and valuable as regards the general plan and arrangement of such buildings, we find, on consulting the chapter on Heating and Ventilation, that the author thinks that carbonic acid is the specially dangerous impurity that is to be gotten rid of, and that this carbonic acid, when cool, falls to the bottom of the room, but as he insists that all foul-air outlets must be at the ceiling, he expects to carry off the greater part of the poison before it has time to settle. Steam heating, he says, cannot pretend to be of use for schools.

He concludes by remarking that medical men seldom speak or write upon the subject without displaying much scientific knowledge, but that their application of such knowledge is not so successful. "The theory of extraction from the bottom instead of the top may be scientifically and theoretically the best, but it is practically inapplicable

to a school house. * * * Extraction from the bottom requires, from its great friction, so enormous a motive power as to be out of the question, except in buildings of very great size."

He does not propose any particular plan for ventilation, but says that "the architect should exercise his own judgment, *and should invariably intrust the carrying out of the work to some engineer specially accustomed to the kind of appliances and arrangements proposed to be used.*" This last passage is a solid piece of wisdom, and as such, I have ventured to italicise it.

Is it strange that the school-house architect should blunder when such is his instruction, or that he should fall an easy prey to the first man who calls himself an "engineer," and urges on him the merits of his patent compound, deflagrating, ventilating, lubricating air heater and purifier?

Within a few years there has been a change for the better, but I am compelled to believe that the majority of architects in this matter go by rule-of-thumb instead of a satisfactory comprehension of the very simple principles involved, and that, moreover, the thumb aforesaid is not of the right dimensions or proportions.

A good illustration of this appears in some remarks contained in the *Builder* of December 4, 1880, p. 667. The writer says that "he was now engaged in superintending the erection of two schools, one of them to be warmed by Mr. Boyd's hygiastic grates, and the other by Leed's American steam-heating system. * * * Unless the air was heated in a direct manner, just as the atmosphere was warmed by the heat imparted to the earth by the sun, or as the air of a room was warmed by the heat given off to it from the objects warmed by the fire, the principle proceeded upon was wrong. It was necessary to keep to direct radiation; in other words, the radiating points must be in the room to be heated, and not in chambers or places remote from it."

From this it would seem that he is satisfied that steam can be used in heating schools, but he thinks that the heating derived from a coil of steam pipe in a room is of the same character and presents the same advantages as that from the rays of the sun, or from an open fire—which is not the case. Heating by a steam radiator in the room to be heated is essentially a system of air heating, for the true radiant heat from such a body is comparatively small in amount and feeble in effect.

I am by no means advising that every architect should endeavor to make himself an expert on the subject of heating and ventilation,

but he ought to know enough of these subjects to be aware of his own ignorance, and to be able to judge of the relative merits of the plans of those who do profess to be experts, and who come to him seeking employment; and also, he should know enough, for the sake of his own reputation, not to be dogmatic in his assertions about the merits of this or that method which he has never seen tried and with regard to which he has no scientific data whatever.

In planning a school house the first things to be considered are the amounts of floor and cubic space and of air supply which are to be allowed each scholar. The class of school houses which we are considering are those of such size and importance that an architect will be called upon to prepare plans and designs for them. They are usually located in cities where space is limited, and the amount allowed for their construction will be insufficient to secure first-class work. Under these circumstances the sanitarian who asks for a liberal allowance of fresh air combined with a comfortable temperature and freedom from draughts, will find that if he sets a high standard his views will be promptly condemned as being impracticable. When the plans are in course of preparation the average board of school trustees will approve of any number of flues and chimneys, but when it comes to giving out the heating contract, and some enterprising steam fitter offers to guarantee perfect heating by placing coils in the school rooms under the windows, for about one-half the cost of such an apparatus as would do the work properly and furnish fresh air at the same time, the said board will, in nine cases out of ten, try the cheap plan, with the usual results.

Let us see what some recent authorities have to say as to the proper amount of air space and air supply for schools. In a report made to the International Congress of Education, held in Brussels in 1880, Dr. De Chaumont discussed these questions fully, and his paper should be consulted as representing the views of European sanitarians on this subject.

Taking, as a starting point, the experiments of Pettenkofer, which show that a man at rest exhales 266 cubic centimeters of carbonic acid per hour for every kilogram of his weight, and making the necessary allowance for the increase due to movement, speaking, etc., he concludes that a child in the school room exhales about 346 c.c. of carbonic acid per hour for every kilogram of its own weight. The average weights of children of different ages being known by Quetelet's tables and De Chaumont's researches (to which I have referred in a previous chapter) having shown that the amount of carbonic acid derived

from respiration should not exceed 2 parts in 10,000, if the odor of organic matter is to be avoided, he has from these data computed the following table:

Ages.	Cubic Meters of Pure Air to be Supplied Per Hour	Cubic Air Space.	No. of Pupils for a Room Containing 315 Cubic Meters.
4 years	25.960	8.650	33
5 "	28.890	9.630	30
6 "	31.320	10.440	28
7 "	34.890	11.630	25
8 "	38.510	12.840	23
9 "	41.670	13.890	21
10 "	45.200	15.060	19
11 "	48.200	16.070	18
12 "	53.630	17.880	16
13 "	61.100	22.370	14
14 "	70.060	23.350	12
16 "	92.200	30.730	9
Adults	118.140	39.380	7

It will be seen that the table is based on the assumption that the air in a school room cannot conveniently be changed oftener than once in 20 minutes, and that, therefore, the cubic space in such a room should be one-third of the amount of air to be supplied per hour. As a matter of fact, this amount of space is not given in the public schools of any country, because of the great expense which it would involve, nor is it a necessity, since the above calculations are based on a supposed permanent occupancy of the room, as in a hospital ward, whereas the school room is occupied but a few hours at a time, and can then be thoroughly aired. The following are the dimensions fixed by law in different countries or recommended by those who have given special attention to this subject, the data being derived from De Chaumont's paper above referred to :

Belgium.—By law 1 square meter of floor space and 4.5 meters in height to each scholar. The Educational League of Belgium, in the plans of its model school, proposes 1.67 square meters of floor space and 5.75 meters in height, giving 9.6 cubic meters to each pupil.

In Holland the average cubic space per pupil is 3.72 cubic meters ; in 89 schools in Haarlem the average per head is 4.54 cubic meters. In England, in the Board Schools, about 1 square meter of floor space and from 3.65 to 4.25 meters in height are allowed for each scholar.

Bavaria prescribes 3.9 c.m. for scholars of eight years and 5.6 c.m. for those of 12 years. The public schools of Dresden give an average of 0.7 square meter of floor space, and 4.38 c.m. to each pupil.

In Frankfort the Medical Society advised 1.84 square meters of floor space, and from 8.5 to 9.2 c.m. per head.

At Basel, in Switzerland, 1.45 square meters, and from 4.21 to 4.67 c.m. per head are prescribed. In Sweden in the primary schools 1.52 square meters and 5.35 to 7.55 cubic meters ; in the higher schools 1.58 to 2.17 square meters, and 7.69 to 9.98 cubic meters per head are given.

In New York City from 2 to 3 cubic meters per pupil are allowed theoretically, but the actual quantity is sometimes much less. Dr. De Chaumont is disposed to lay some stress on the question of age and to take the ground that young children require much less air space and air supply than adults, as they produce so much less carbonic acid. He would, for example, put three times as many children of four or five years of age as of youths of 15 or 16, in a given room. This seems to me to be very doubtful. The question of amount of carbonic acid exhaled has little or nothing to do with the matter, except in so far as it is an index of the amount of organic matter given off, and it is probable that the difference between the amount of organic matter excreted by a child of five and one of 15 is by no means so great as would be indicated by the carbonic acid test. I should allow in a school room or hospital very nearly the same amount of air supply per head for children of all ages over five years as for adults. The dimensions of the school room recommended by Dr. De Chaumont are 10x7 meters, and 4½ meters in height, and in such a room he would place from 12 to 53 scholars, according to their ages.

In connection with the paper of Professor De Chaumont, above referred to, the transactions of this congress contain essays by M. Wazon, a French engineer, and M. Dekeyser, a Belgian architect, upon the methods of heating and ventilating schools. M. Wazon takes 20.5 cubic meters as the allowance of fresh air per hour per head. M. Dekeyser allows from 20 to 30 cubic meters, according to ages.

Prof. W. Ripley Nichols, of Boston, in a report on the sanitary condition of certain school houses in that city, dated March 23, 1880, fixes as the permissible amount of carbonic acid in school rooms 1 part by volume in 1,000, and while tacitly admitting that this is a low standard, says that it is as high a one as can at present be insisted on. " With this amount of carbonic acid there will undoubtedly be more or less of the ' school odor,' especially with a certain class of the scholars.

To obviate this entirely would require an amount of fresh air which could not be practically introduced into a building constructed as the Sherwin School is ; in case of new buildings a higher standard might be obtained, say, 0.8 or 0.9 volumes of carbonic acid in 1,000 volumes of air ; but it is doubtful whether this standard could be reached without a larger amount of floor space than the 15 square feet usually allowed."

The amount of carbonic acid which Professor Nichols actually found in the school rooms of the Sherwin School varied from 1.43 to 2.29 parts per 1,000.

The standards which I would fix for space and air supply in schools are those given in the report of the special committee on plans for public schools, given in *The Sanitary Engineer* for March 1, 1880, and reiterated in the report of a commission on the public schools of the District of Columbia, dated March 15, 1882, and printed as Mis. Doc. No. 35, House of Representatives, Forty-seventh Congress, First Session—viz.:

" In each class room not less than 15 square feet of floor area shall be allotted to each pupil.

" In each class room the window space should not be less than one-fourth of the floor space, and the distance of the desk most remote from the window should not be more than 1½ times the height of the top of the window from the floor.

" The height of the class room should never exceed 14 feet.

" The provisions for ventilation should be such as to provide for each person in a class room not less than 30 cubic feet of fresh air per minute, which amount must be introduced and thoroughly distributed without creating unpleasant draughts or causing any two parts of the room to differ in temperature more than 2° F., or the maximum temperature to exceed 70° F."

It must be remembered that the above represents the minimum of requirement, and is based upon the requirements in cold weather. In warm weather, when the incoming air need not be heated, the supply should be as great as open windows and doors can be made to furnish.

The usual requirement of those schools in this country for which the architect will be called in to prepare plans, will be that they shall contain from eight to 12 class rooms, each of which is to accommodate from 40 to 60 pupils, and that these are to be arranged in connection with a large central hall in a two-story brick building.

In some cases there will also be required one large assembly room, which is usually placed in a third story. The heating will be effected by furnaces or steam, the tendency being to increased use of the latter.

The trouble with furnaces is that they are almost invariably set in insufficient number, and are of too small a size.

To undertake to heat such a school house as that above described with one or two furnaces is to insure bad ventilation. Not less than four furnaces are necessary in such a building, and these must be of the largest size, giving a large heating surface, costing from four to six hundred dollars each when properly set.

A properly arranged and well constructed steam-heating apparatus for such a building will cost from four to six thousand dollars, depending on the exposure, etc. Cheap steam heating is more objectionable than a furnace. As a rule, school rooms are overheated, the temperature in winter in our schools ranging usually from 72 degrees to 76 degrees. The rule should be that the temperature should never exceed 70 degrees, and Dr. Lincoln is no doubt correct in his statement that children can be made comfortable at 66 degrees in a well-aired room.

The sensations of the teacher rather than those of the scholars usually govern the regulation of the temperature, and, as Dr. Lincoln remarks, "an interesting lesson may be going on, or a written examination; the mind works well, for a time, at a fever heat, and the temperature of 84 degrees may pass unnoticed. It is needless to say that such a strain upon the system is followed by a period of lassitude, and a state of lassitude again may demand a slightly raised temperature. Thus, by degrees, habits of preference for hot rooms may be found. The teacher may be as unconscious of the evil as the scholar ; indeed, if fatigued she may require, or if excited may not notice, an unusual heat. The time to correct bad habits in this respect is the beginning of the school year. Every one then comes to school with a system invigorated by some months of exposure to fresh air, and if care is taken, this vigor or power of resisting cold may be retained." To this I would add that a slight modification of the alarm thermometer, which arouses the keeper of a greenhouse by the ringing of a bell when the temperature falls below a certain point, can be easily applied to secure the constant ringing of an alarm whenever the temperature rises above 70 degrees, and that such an instrument would be a very useful reminder and not very costly.

The arrangements for ventilation of school houses by architects relate, as a rule, mainly to the removal of foul air, not sufficient attention being given to amount and location of fresh-air supply. A common method of construction of late years is to provide an eight or 12-room school building with two or four aspirating shafts or chimneys connecting with the various rooms and having an aggregate capacity

sufficient, with a velocity in these shafts of about 8 feet per second, to remove from 15 to 30 cubic feet of air per head per minute. The air supply in these same buildings is to come from a few 9-inch flues, or, as in the Washington school buildings, through narrow slits placed beneath the window sills. The plan in the Washington buildings was so very bad, and yet was so highly approved by some persons, that it seems worth a little more detailed description. The fresh air is admitted through a perforated iron plate, set in the walls beneath the sills of the four windows in each room. The sum of the area of clear opening in the external plate of each window is from 22 to 25 square inches, making a total opening for the supply of pure air for the room from 88 to 100 square inches, or about two-thirds of 1 square foot, which would not give 5 cubic feet per minute per pupil. Having passed through the perforated plate above referred to, the air is supposed to pass downward through a narrow slit in the wall, until it reaches the level of the floor, when it turns inward, and then passes up through a steam radiator set against the window breast. Very little air comes through such an arrangement in comparison with what is required, but even this little is carefully shut out in cold weather to prevent draughts and the freezing of the pipes.

This method of heating a school room by steam pipes placed in the room, is almost sure to involve a defective air supply, yet it is one that is peculiarly attractive to those who are not qualified to judge of the relative merits of various methods of heating, since it is comparatively cheap and does give the requisite amount of warmth.

The practical effect of such a system when connected with a large aspirating shaft is that a large part of the air supply in the class rooms comes from the central hall, as will be seen by testing the direction of the currents at the doors and transoms. This central hall, in turn, derives a large part of its air supply from the basement by means of the stairways. This basement air is liable to be rendered impure by the furnace, and by the water closets, if they are placed in it, which should never be the case.

First of all, then, in planning a school house, consider the air supply. With regard to the location and direction of the openings in the school rooms for the admission of fresh air, they should either be situated above the heads of the occupants or be so placed as to give an upward current, for the amount of floor space which can be afforded to each pupil is so small that some of them must be placed in unpleasant proximity to registers located near the floor in the ordinary way. The usual location, and one which gives good results if

the fresh-air flues and registers are large enough, is to place them on the outer walls, in which case the window sills are a convenient place for the registers. Mr. W. R. Briggs proposes to introduce the fresh air on the inner wall at a point about two-thirds of the distance from the floor to the ceiling, and has constructed at Bridgeport, Conn., a high school upon this principle.

A description of the heating and ventilation of this building was published in the Third Annual Report of the Connecticut State Board of Health, and a part of this appeared in *The Sanitary Engineer* for December 1, 1881, from which I take the following description and illustrations:

"In the Bridgeport school the coil chambers for the heating of the various rooms have been placed in the main ventilating shafts in the *center* of the building, and the air is conveyed from them through these shafts to the rooms by means of metal flues. The air enters the inner corner of the room, about 8 feet from the floor. The outgoing flue has been placed directly under the platform, which is located in the *same corner* as the introduction flue. This platform measures 6x12 feet, and is supplied with castors, so that it can be moved at any time it is necessary to clean under it. Its entire lower edge is kept about 4 inches from the floor, to give a full circulation of air under it at all points. The action of the incoming air is rapidly upward and outward, stratifying as it goes toward the cooler outer walls, thence flowing down their surfaces to the floor and back across the floor to the outgoing register on the inner corner of the room. By this method all the air entering is made to circulate throughout the room before it reaches the exhaust shaft, and there is a constant movement and mixing of the air in all parts of the room continually going on.

"The inlets are all intended to be large, and the flow of air through them moderate and steady. The air is not intended to be heated to a very high temperature; the large quantity introduced is expected to keep the thermometer at about 68 degrees at the breathing level. The school rooms contain on an average about 13,000 feet of air, or 260 cubic feet per pupil. It is proposed to supply each pupil with 30 cubic feet of air each minute. Allowing 50 pupils to each room, this will necessitate the introduction of 90,000 cubic feet of air into the room each hour, and will change the air of the room 6.92 times within the hour, or once in about eight minutes. These calculations are based on a difference of 30 degrees in the temperature.

"In the exhaust flues there are placed coils to produce a strong up current at all times; heat is also obtained from radiation from the boiler flues, which run through the foul-air shafts.

"The heating surface for each room is inclosed in separate cases or jackets of metal, and is then subdivided into five sections, so arranged that any number of sections or the whole may be used at pleasure—that is to say, that any one, two or more, up to five parts, may be used at discretion. In extreme cold weather the whole five sections are in use; in moderate weather two or three, and when a small amount of heat is required, only one. By this plan the supply of pure air remains always the same, but the degree to which it is heated is changed by the opening or closing of a valve."

This arrangement is shown on the accompanying vertical section of a coil chamber, which represents the actual construction of the coil and chamber, *A B C D E F*, on the section of building.

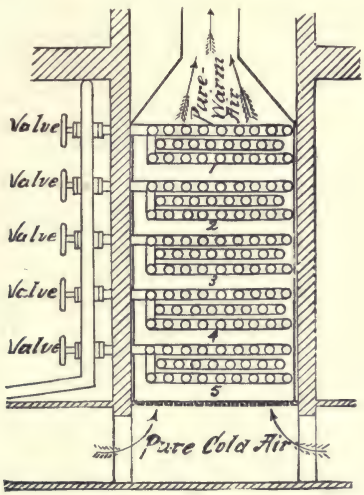


FIG. 155.—VERTICAL SECTION OF COIL CHAMBER.

These large dimensions for the outlet shaft have further support in the mind of the architect in the necessities for summer ventilation.

The results obtained from this arrangement are indicated in the report of an examination made by Dr. Lincoln, which report will be found in *The Sanitary Engineer* for January 11, 1883.

The large opening, shown in the plan at the left of the platform, is into the assembly room through folding doors, and the smaller on the right into the hall. The circles on the plan indicate the position of thermometers, and the numbers beside them are those used in the following table. Where two numbers are attached to one circle, there were

two thermometers, one above the other. No. 1 was at the center of the hot-air register, about 8 feet above the floor; Nos. 2 and 3 at a

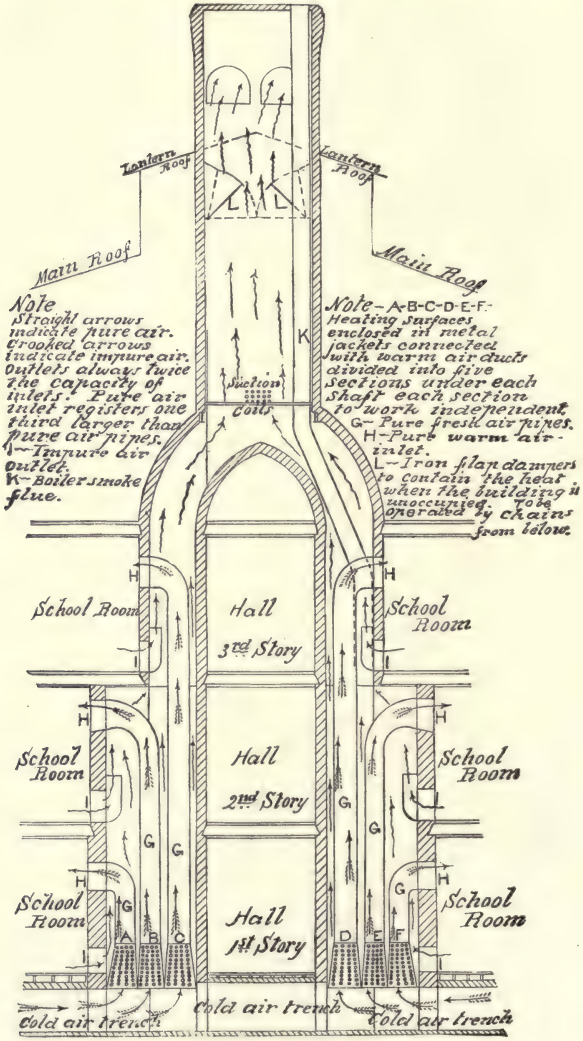


FIG. 156.—VERTICAL SECTION OF SCHOOL BUILDING.

height of 12 feet above the floor (about as high as the instrument could be placed in a vertical position); Nos. 4, 5, 6, 7, 8, 9, 10 and 11

at a height of 5 feet 6 inches—level of bulb; and Nos. 12, 13, 14 and 15 at 1 inch above the floor, No. 15 being in front of the outlet.

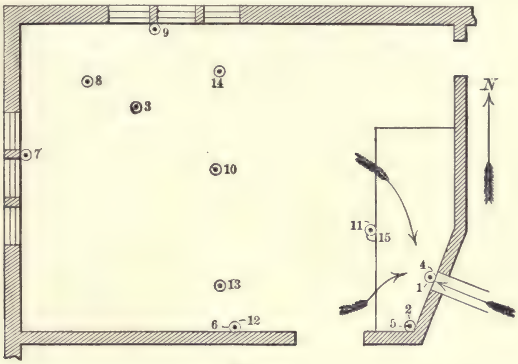


FIG. 157.

The thermometers used were said to have been carefully selected and compared with each other, and to have had no great variation. The room had been closed (before the afternoon observation) at 12.40. A class of about 50 scholars—the full number—was admitted at 3 o'clock, and dismissed 25 minutes later.

Number of Thermometer on Plan.	DECEMBER 22, P. M.					DECEMBER 23, A. M.		
	2h.40m.	2h.50m.	3h.10m.	3h.25m.	4h. 0m.	9h. 0m.	9h.40m.	10h.7m.
1	108°F.	112°	120°	120°	119°	90°	104°	135°
2	74	76	80	81+	84	......	70	80
3	75	78	84	85	87	......	67	79
4	69	70	73	75	76	61	63	68—
5	69	71	74	76	77	61	63	69—
6	69	71	74	75	77	60	62	69
7	71	73	76	78	79	60	63	72
8	68	70	73	75	......	......	......	......
9	70	72	76	77	78	60	62	71
10	69	71	75	76	78	60	63	69
11	70	72	76	77	79	61	63	70
12	67	67	......	70	......	......	......	......
13	66	67	70	......	......	......	60	62
14	65	65	......	69	69+	57	59	60
15	68	69	71	73	......	......	61	64
Outside	......	37	......	36	......	41	......	......

Two measurements were made of the amount of air coming in. The first, at about 2.50, showed nearly 800 cubic feet per minute, and

the second, at 3.15, nearly 1,000 cubic feet per minute, or 20 cubic feet per pupil.

In the words of Dr. Lincoln, "abundant proof was given that the current passes very rapidly across the ceiling, quickly down the exposed (outer) walls, then slowly back across the room to the outlet; the range of temperature, regularly falling in about this order, furnishes a proof of this, and further evidence was fully given by the action of the anemometers at the ceiling and at the outer exposed faces of the room.

"In the latter situation, the current was invariably downward, and the elevated temperature at the windows will be noticed.

"To answer a question as to the temperature at the level of the pupils' bodies, a thermometer was placed upon a desk at 14. In the last two trials (right-hand columns) the readings of Nos. 3, 9, the new thermometer, and 14 (respectively placed at the ceiling, at 5½ feet from floor, at the desk level, and at the floor), were 67, 62, 60, 59 degrees; and 79, 71, 63 and 60 degrees."

The motive power for ventilation of ordinary medium-sized school buildings may be furnished by fans, or by an aspirating shaft or chimney, but as a rule two of the latter, one on either side of the central hall, are to be preferred if aspiration only is to be employed. The size of these shafts will be determined by the fact that the velocity in them should be from 6 to 8 feet per second. Knowing the total amount of air to be moved per second, the calculation is very simple. If it be decided to use but one large aspirating shaft for the whole building, the best results will be obtained by carrying all the foul-air flues downward, and having them open at the bottom of the shaft.

Of late years the use of fans in school-house ventilation is becoming common, and excellent results may thus be obtained. The hot-blast system is better adapted for use in schools and office buildings than it is for buildings which are permanently occupied, and two examples of its use are here given.

The new Jackson School building in Minneapolis is of brick, 90x130 feet, three stories high, intended to accommodate 1,056 pupils, and is warmed and ventilated by a hot-blast system which delivers the fresh air into the rooms through openings 2 feet square placed about 6 feet above the floor. It was required that the heating plant should raise the temperature from minus 40° to plus 70° F., and maintain the same as long as required; and that the ventilation plant should furnish 3,000,000 cubic feet of fresh air per hour, warmed to 70° F.

Figure 158 is a plan of the ground floor containing the boys' manual training rooms, *B C K*; water closets *A D*; class rooms *E F I J*; fuel room *H*, and boiler room *L*. The steam pipes are

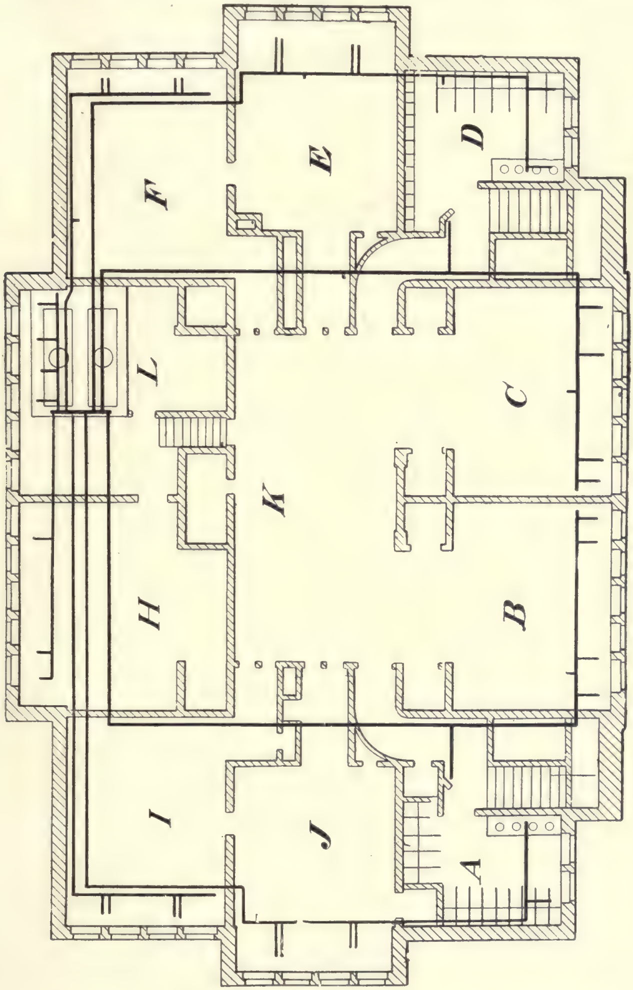


Fig. 158.

run overhead, and are here indicated by heavy full lines for the direct mains, and by heavy broken lines for the dry returns to boiler room.

Figure 159 is a plan of the main floor. *A* is a calisthenics hall, and there are eight class rooms and two recitation rooms. The second

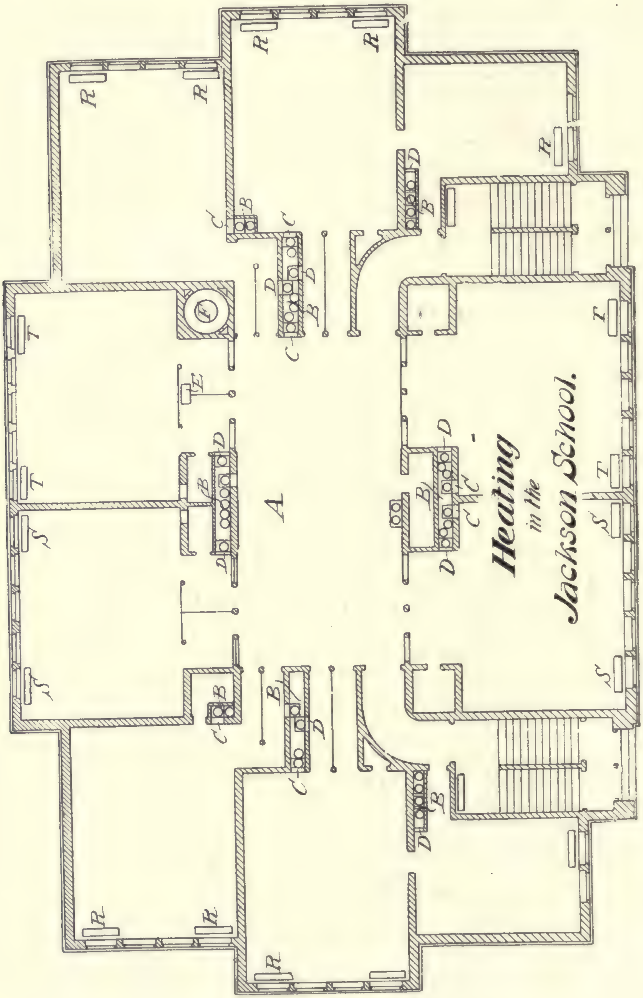


FIG. 159.

floor is similar to the first. *R R*, etc., are direct steam radiators, chiefly of the Haxtun make, of wrought-iron pipe, standard height. *S*

S are Detroit radiators, 60 inches long and of standard height. *T T* are Joy draft tube radiators, 37 inches long. *B B*, etc., are heating and ventilating shafts that contain separate cylindrical, galvanized-iron flues for each room. Their openings, *C C D D*, etc., measure for the class rooms 2x2 feet, and for the recitation rooms 2'x1'4". *E* is the belt shaft for the exhaust fan.

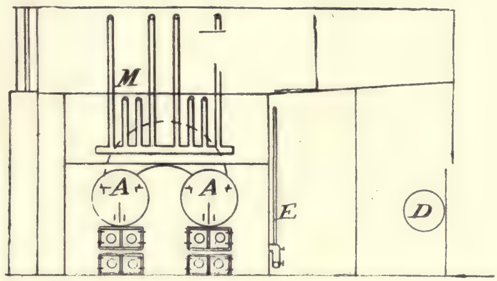


FIG. 160.

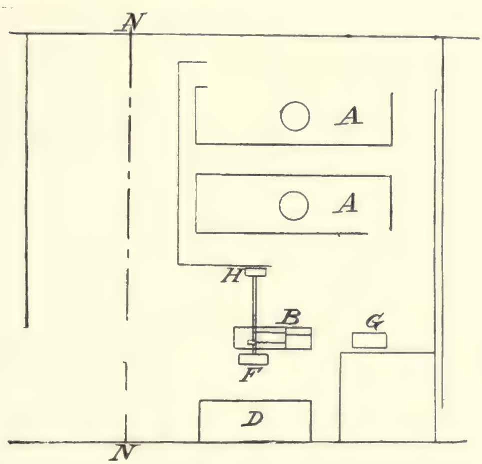


FIG. 161

Figure 161 is a plan of the boiler room *L*, Fig. 158. Figure 160 is an elevation at *N N*, Fig. 161. *A A* are 48"x14' steel, tubular boilers. *B* is an Atlas, self-contained, 15 horse-power engine, with pulley *F* vertically under the attic exhaust fan, which it drives by a belt.

The pulley *H* drives the fresh-air fan in an adjacent room. Both fans are Kelley Excelsiors, 72 inches diameter, made by the Preble Machine Company, Chicago.

The pressure fan delivers fresh air to the indirect radiator stack, made by the Haxtun Steam Heating Company, of Kewanee, Ill. This stack contains 4,752 feet of 1-inch pipe, made into six radiators, 60 inches long, with standard bases and supply and return connections at opposite ends, and without tops or legs. *G* is a Worthington duplex boiler feed pump. *D* is a 30″x8′ return tank with manhole and hand-hole.

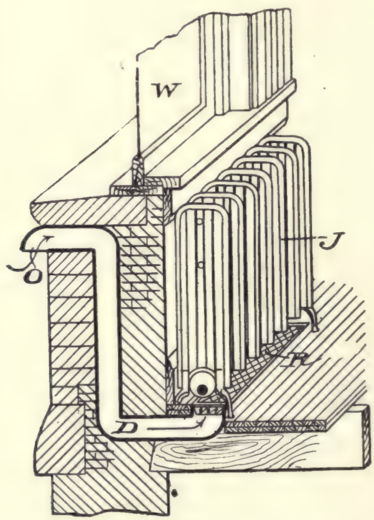


FIG. 162.

Figure 162 shows the method of setting Joy draft tube radiator *J*, here used, so as to obtain direct radiation when ventilation is not required, leaving the ventilation under the control of the occupant of each room. Fresh air is admitted through an opening *O* beneath window *W*, and delivered through a galvanized-iron duct *D* to the register *R*. This controls its admission to the room.

Further details in regard to the heating apparatus of this school are given in *The Engineering Record* of June 9 and June 20, 1891.

The cost of the steam heating, ventilating and flue work is given as $7,214, and it requires about one ton of Illinois coal per day.

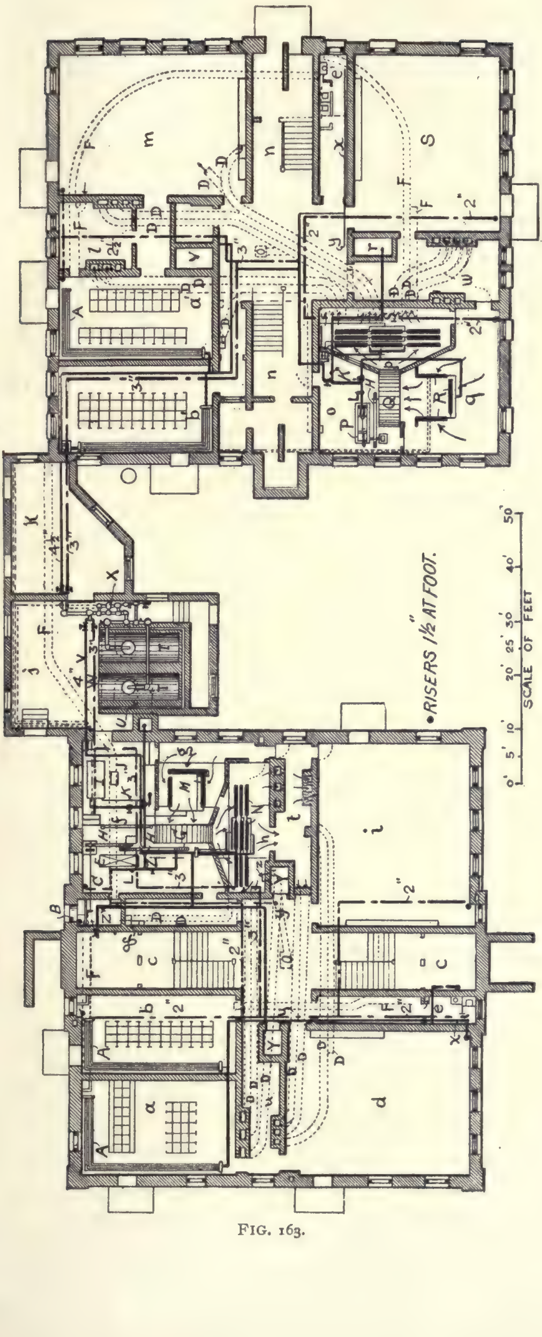


FIG. 163.

Figure 163 is a plan of the basement of the Garfield School in Chicago, which school consists of two buildings, each of three stories and basement, and containing 12 class rooms.

The reference letters indicate as follows: *A A*, etc., ceiling coil radiators of 1¼-inch pipe, *B* a 36-inch exhaust fan, *F F*, etc., are galvanized-iron foul-air ducts, from closet rooms only, of rectangular cross-section, generally 18x20 inches, or of equivalent sectional area, and carried on the ceilings. These are concentrated in a chamber in front of a 36-inch exhaust fan. *F* is an 8x12-inch Atlas engine of 15 horse-power (indicated), which drives shaft *C* and the 72-inch Sturtevant blower *G* through belts *H H*. *D D* are fresh-air ducts to class and recitation rooms, similar to *F F*, etc. *I* is a return tank and *J* is a 5¼′x3½′x5″ Worthington duplex pump for boiler feed water and house supply. *K* is a pressure-regulating valve, and *L* is a grease trap. At *M* are three primary radiators, each 4′x32′x6″ high, having a combined total surface of 768 square feet, and placed on a platform 36 inches high. At *N* are nine secondary radiators, each 4′x32′x6″ high, and having a combined surface of 2,304 square feet. *O O* are first-floor registers.

P is an 8x12-inch Atlas engine of 15 horse-power (indicated), driving through belt *H* the 72-inch Sturtevant blower *Q*. At *R* are three primary radiators, each 4′x32′x6″ high, with a combined surface of 768 square feet, and placed on a platform 2x6 inches above the floor. At *S* are nine secondary radiators, each 4′x32′x6″ high, and having a combined surface of 2,304 square feet. *T T* are two 54x14-inch steel boilers, made by the John Davis Company, each containing 39 4-inch tubes. *U* is the smoke-stack; *V* is the indirect and *W* the direct steam main; *X* is the pressure regulator, *Y* and Y^1 are the old brick ventilation shafts that now contain separate galvanized-iron flues from different rooms, and are extended up through to the top of the roof. *Z Z* are risers to supply steam to the direct radiators in the upper stories, each horizontal branch being connected to one wall coil with generally 104 square feet of surface of 1¼-inch pipe.

The indirect supply mains are shown throughout by full black lines, and the direct supply mains by lines broken with one dot.

a and *a′* are the boys' and *b* and *b′* are the girls' water closets, *c c* is a hall which is used for a passageway, *Z* is the exhaust chamber for foul-air flues from the closets in which the 36-inch fan is placed, *d* is a boys' play room, *c* and *c′* are teachers' toilet rooms, *f* is the engine room, *g* is the cold chamber to which fresh air (as indicated by the arrows) is admitted through adjacent external

windows, and passing through radiators *M* and the blower *C* is forced through radiators *N* in the hot chamber *h* and into the distributing chamber *t*, which has been adapted from an old brick chamber for a furnace, up whose original flues, together with those of the other furnace at *u* (which are connected by galvanized-iron ducts) the hot air is delivered to the upper stories. Continuing, *i* is a play room, *j*, boiler rooms, and *k* is a coal room. The old brick foul-air

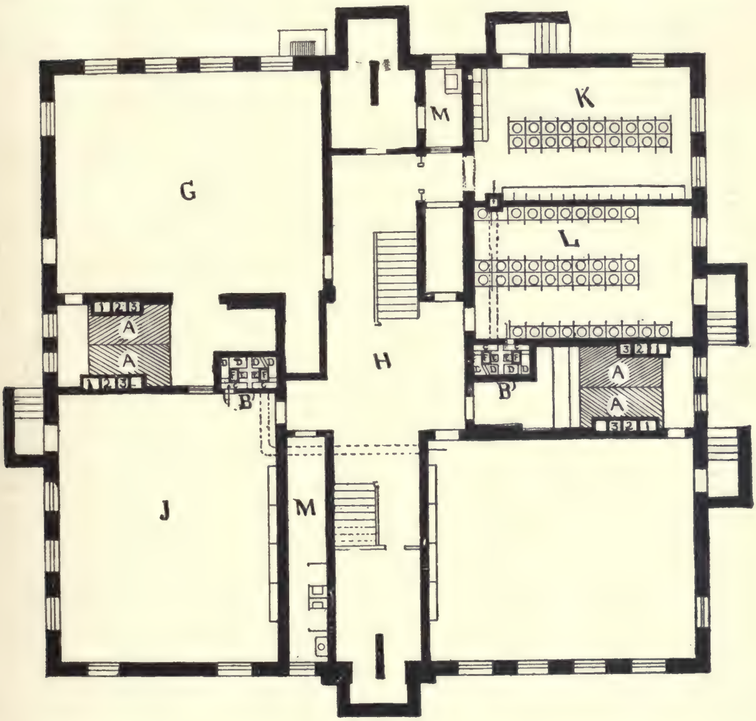


FIG. 164.

flues formerly used in connection with furnace ventilation are now used. A separate flue *l*, extends from each class room to the top of the roof. In this figure, *m* is the girls' play room; *n n*, a hall; *o*, engine room; *q*, the cold-air chamber in which the fresh air is received, as indicated by arrows, from adjacent external windows, and drawn through radiators *R* by blower *Q*, which forces it through radiators *S* in the hot chamber *p* and thence through galvanized-iron ducts

to the flues of the original hot-air furnaces at *l* and *w*; *p* is a vertical shaft into which the exhaust pipe from engine *P* is taken up to the top of the same; *s* is a play room, *x x* are 1½-inch horizontal direct steam pipes to risers for wall coils, and *y y* are upright branches to radiators on the first-story hall.

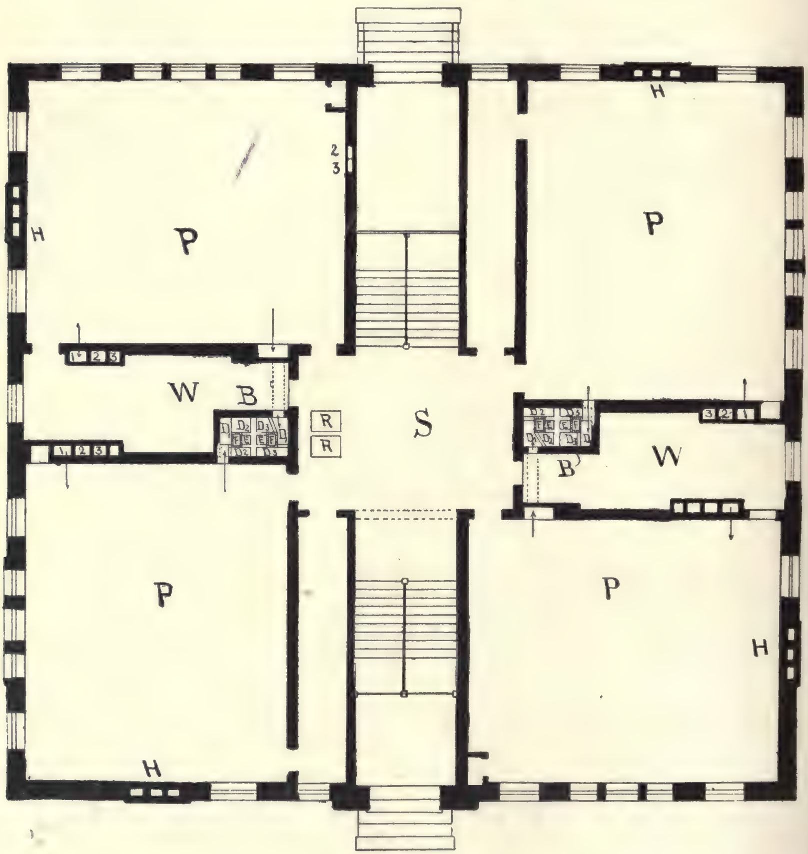


FIG. 165.

Figure 164 is a plan of the basement of the old part of the Garfield School, showing the original arrangement of heating by the furnaces *A A*. *B B* were ventilating shafts; *G*, the coal room; *H*, hall; *I*, girls', and *J*, boys' play room; *K*, boys' and *L*, girls' water closets; and *M M*, teachers' toilet rooms.

Figure 165 is a plan of the first story of the old part of the Garfield School, showing the original arrangement. Warm air from the furnaces was admitted from the flues marked 1, 1′, etc., while those marked 2 and 3 delivered it to the second and third stories, respectively. Foul air was withdrawn, as indicated by arrows, upward through the ducts *D D*, etc., of ventilation shafts *B B*, the ducts

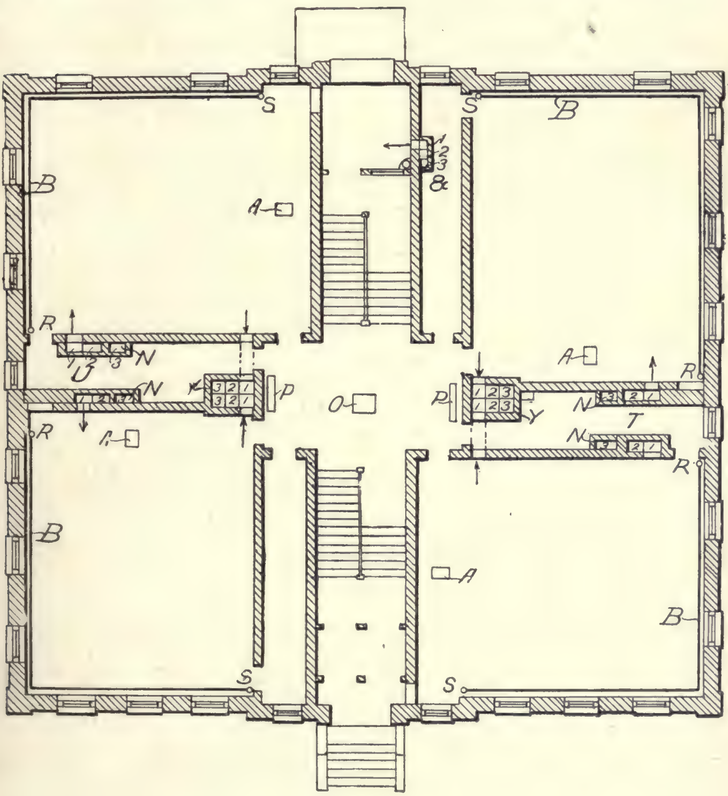


FIG. 166.

D_2 D_3 serving for second and third stories, respectively, *E E*, etc., serving the basement closets, and *F F*, etc., being the radiator ducts which accelerated by conduction the circulation in the adjacent ducts. Rectangular tin foul-air flues between basement ceiling and first floor connected remote class rooms with flues *D D*, and are here shown by dotted lines. *P P*, etc., were class rooms; *W W*, wardrobes; *S*, hall,

and *R R* registers 27x38 inches. *H H* are auxiliary wall flues for ventilation.

Figure 166 is a plan of the first floor of the old part of the Garfield School, showing present arrangement. *Y Y U T* and *&*, are the same vertical lines of ducts and flues that are indicated by the same letters in Fig. 163, those at *&*, *U* and *T*, delivering fresh air and comprising three separate ducts each, which terminate at the first, second, and third stories, respectively, as indicated by the corresponding numerals which show which floor they serve. At *U* and *T* the original single duct has been divided by galvanized-iron partitions, as shown, to make separate passages for each room, and an additional galvanized-iron

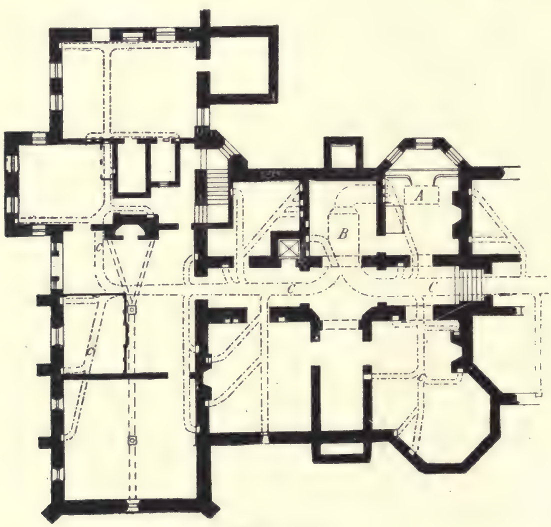


FIG. 167.

flue *N*, has been added alongside for the third-story rooms. Ducts *&* have been especially built of galvanized iron. Similarly six galvanized-iron flues have been placed in old shafts *Y* and *y*, to afford separate service to the different rooms, two in each shaft, terminating at each of the three upper floors. All of these opening are provided with registers, those for warming being near the ceilings and those for ventilation being near the floor. *O* is a hot-air register, and *A A*, etc., are old registers now closed. *B B*, etc., are supplementary direct radiator coils, each of about 100 square feet and connected as shown to supply and return steam risers *S* and *R*.

For further details see *The Engineering Record* for December 19, 1891, and January 2, 1892.

As an example of a boarding school heated and ventilated by a hot-blast system, I give the plans of part of the Bryn Mawr school near Philadelphia, for which I am indebted to Mr. Jellett, the engineer of the Steam Engineering Company, of Philadelphia.

Figure 167 is a plan of that part of the basement containing the heating apparatus. *A* is the blowing fan, having an outlet 38 inches square. *B* is the heating coil, with 1,400 square feet of heating surface. The main air duct from this coil is 45 inches in diameter and divides into two ducts, one 32 inches and the other 31 inches in

FIG 168.

diameter. The 32-inch branch is 210 feet long and supplies 59 vertical flues varying in size from 4x12 inches to 6x14 inches. The 31-inch branch extends 112 feet and supplies 24 vertical flues varying in size from 5x12 inches to 6x15 inches.

Figure 168 shows arrangement of first and second floors, the points of delivery and exit of air being indicated by arrows.

Figure 169 is a plan of part of the third floor and loft, showing foul-air ducts *C C*, uniting to deliver into a large vertical tower shaft.

All rooms not supplied with fireplaces and chimney flues have upcast foul-air flues. In the tower shaft is an accelerating steam coil heated by steam at 50 pounds pressure.

The steam heating and ventilating apparatus in the building of the College of Physicians and Surgeons, of New York City, was arranged by Mr. William J. Baldwin, and presents some features of special interest. Both hot and cold-air ducts are carried to each room, except the amphitheaters and dissecting room, so that the temperature of the room can be controlled by the occupant. Four fans, each 6 feet in diameter, are used, two of them furnishing air slightly warmed, or with the chill off, and two air-heated to the usual degree. The mode in which the twin ducts are arranged is shown in Fig. 46, page 270.

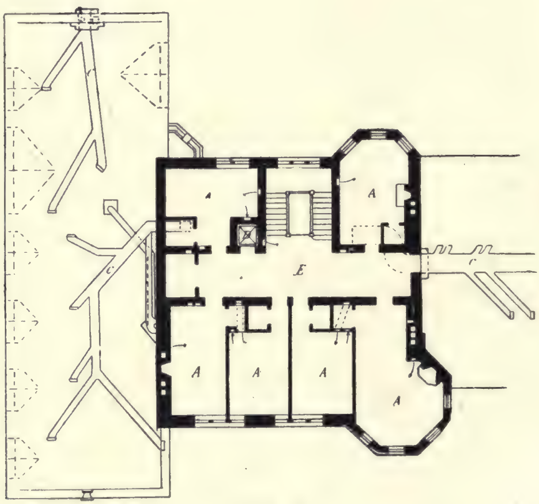


FIG. 169.

Figure 170 shows the general cellar plan and a vertical, longitudinal section through the middle building of the group of three, and shows the main features of the whole system.

The fans, four in number, are each 6 feet in diameter, and from 1,000,000 to 1,250,000 cubic feet capacity each, according to the speed at which they are run. All the engines and pumps exhaust into a 5-inch main exhaust pipe which extends to the roof of the building. A branch from this pipe leads to a feed water heater and back again into the pipe. Another branch, 5 inches in diameter, supplies exhaust steam to the coils in the casings *A A' B C D G* and *L*, after the steam has been passed through a "skimming tank," where the oil from the engines is separated from it. These coils are of the gridiron

type, made up of a number of sections each. The sections have an average length of 10 feet, not including the spring pieces, which measure about 2 feet. The pipes of the coils are covered with secondary

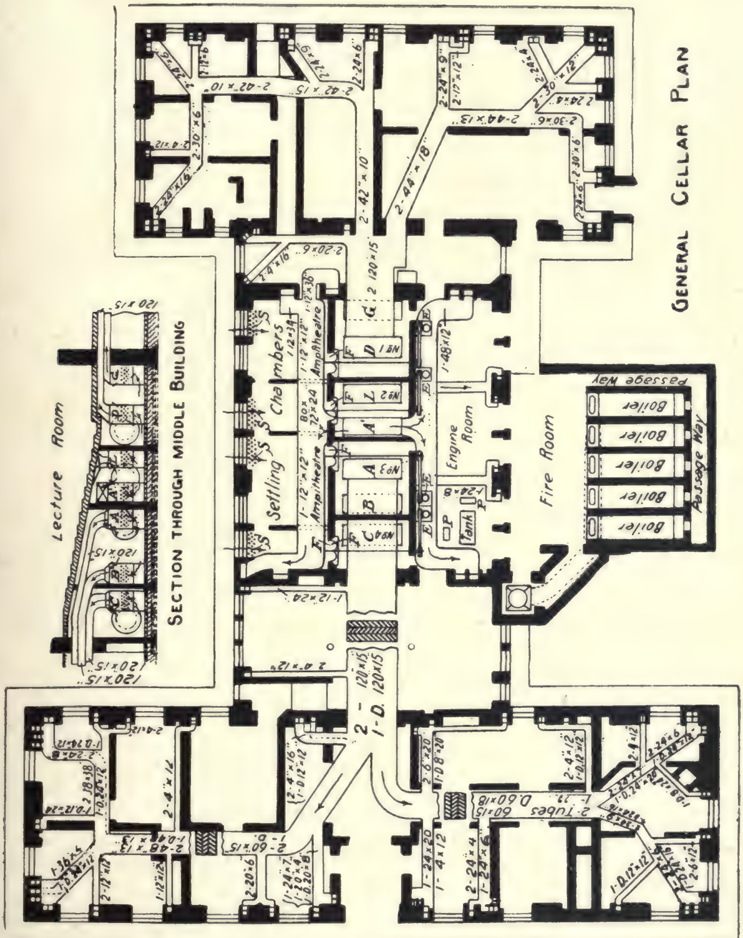


FIG. 170.

wire surface, made of No. 14 square iron wire, and known as Gold's compound coil surface. The coil stands are made of pipes and fittings and are so arranged that each section can be drawn out for repairs

without disturbing those others. Each section, moreover, is fed separately by a 2-inch steam pipe with a valve in the engine room, and the return pipes also come separately into the engine room. The coils are inclosed in galvanized-iron casings, open at the bottom, and connecting with the air ducts at the top, as shown more clearly in the vertical section. Swinging dampers are arranged in the bottoms and near the tops of these casings, so that a mixture of hot and relatively cold air may enter the distributing ducts, the proportions being readily controlled by opening or closing the different dampers.

In front of the four fresh-air inlet windows primary steam coils *S*, supplied with live steam, are set up. These coils aggregate about 1,600 lineal feet of 1-inch pipe, covered with secondary wire surface, as in the case of the main heating coils. The entering air, which thus receives what may be called an initial heating, reaches the settling chambers, marked on the plan, and from these is drawn by the fans into the four heating chambers, containing the coils and casings *A A′*, *B C D L* and *G*. The coils *B* and *G* are not ordinarily supplied with steam, but are designed to be used as substitutes for the coils *A* and *D* in case of repairs, in which case the "warm" duct would be used as the "hot" one. It should be remembered, also, that the air ducts from *A* and *B* and from *D* and *G* together lead to twin flues and discharge into the same rooms. The air which passes into the casings *B* and *G*, therefore, is not further heated, but is simply at that comparatively low temperature which has been imparted to it in passing through the primary coils. The air which passes through the casings *A* and *D*, on the other hand, is further heated to the much higher temperature due to the hot coils within. The hot and warm-air supplies from the casings *A* and *B* and *D* and *G*, discharge into the same register boxes, as already intimated, and the proportions of each may be varied by special slide valves at the register face. These valves or dampers are so constructed that they will allow the air from one of the twin flues to escape separately, or admit a part of the air from each flue, one flue opening in the proportion the other is closed. Two streams of air of different temperatures may thus be admitted to the register box, where they mix and then pass through the register face, and, at the same time, it is beyond the power of the occupants of the rooms to shut off both pipes at the same time. The ducts leading in the dissecting room, amphitheater and lecture room, from the casings *C A′* and *L*, supply only warm air, the temperature of which is regulated by the engineer, the double-duct system not being used for these. The lecture-room duct, as shown in the vertical section, discharges

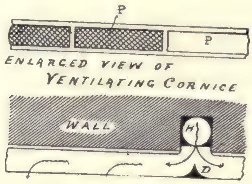


FIG. 171.

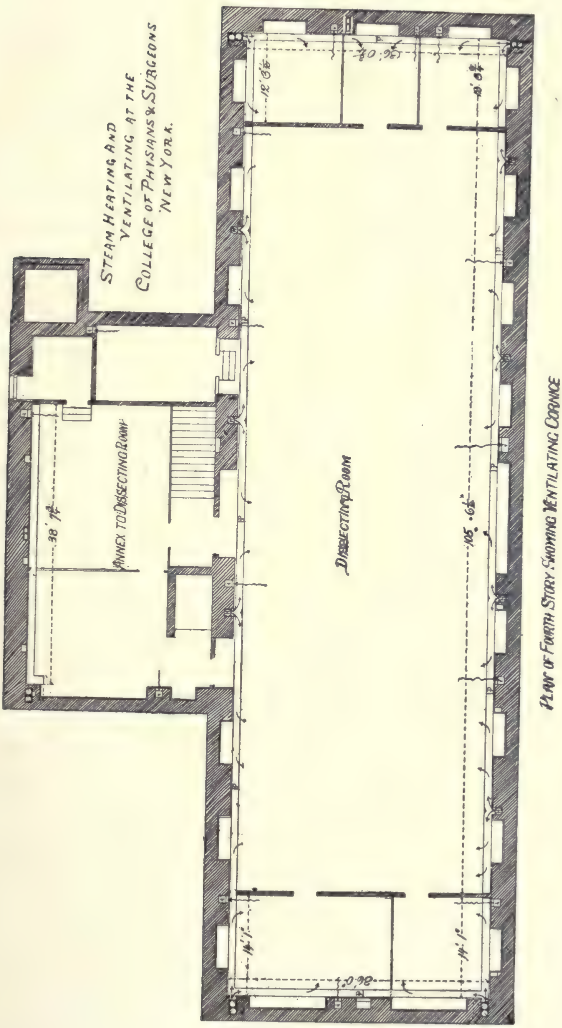


FIG. 172.

into the space under the seats, and from there the warm air issues into the room through openings in front of each row of seats. The warm-air discharge into the amphitheater is effected in the same way.

Figure 172 is a plan of the dissecting room on the fourth story. The hot-air flues pass up to the galvanized-iron perforated cornice,

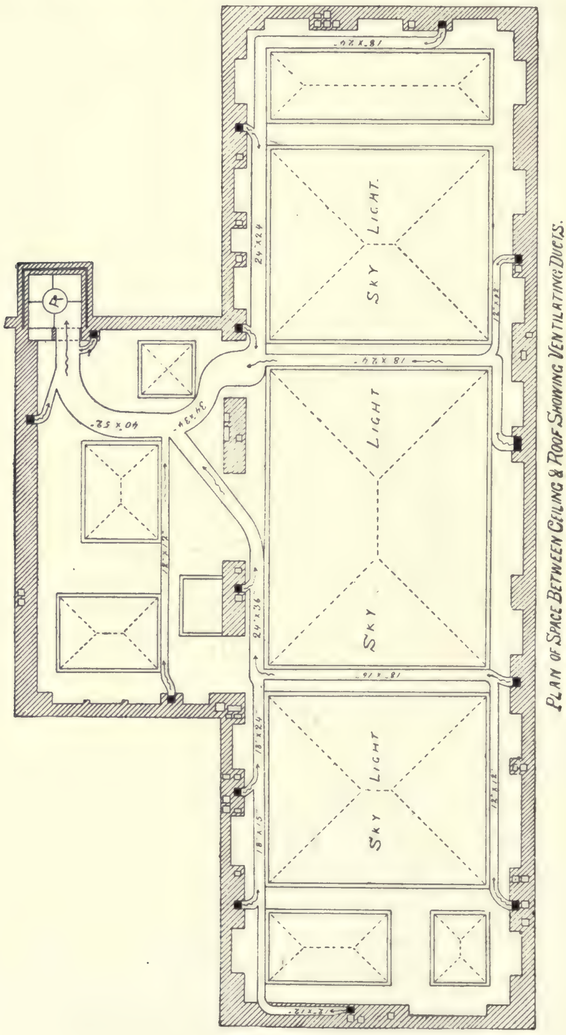


FIG. 173.

shown in Fig. 171. Opposite each flue opening is a deflector *D*, Fig. 171, to turn the air along the line of the cornice, and thus secure diffusion of the incoming currents.

Figure 173 is a plan of the space between the ceiling of the dissecting room and the roof. The hot air from the ventilating cornice becomes chilled by the glass of the skylights and descends to the floor, where the openings of the foul-air ducts are placed.

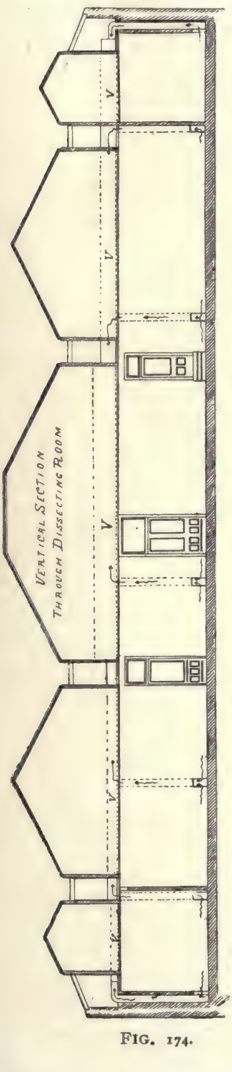


FIG. 174.

Figure 174 is a vertical section of the rooms in which the foul-air ducts *V* are shown. These ducts join and lead to the aspirating shaft *A*, as shown in Fig. 173.

Figure 175 is a perspective view of the direct-indirect hot-water radiators in a fourth-floor class room of the Berkeley School in New York, and Fig. 176 is a section of one of these radiators. The fresh air enters the flue *A*, through the grating *B*, the quantity admitted being controlled by the damper *D*. Figures 177 and 178 show similar arrangements in other class rooms.

In this building the motion of the air is produced by an aspirating fan in the attic drawing from wall flues opening into each room.*

In concluding this part of the subject, attention is called to the fact that whatever be the system of ventilation adopted, it should be supplemented by daily, systematic and thorough aeration of the building morning and evening. No doubt this will chill the rooms in cold weather, and will increase the expenditure for fuel, but this is a necessary and legitimate expense.

In 1888 the State of Massachusetts enacted that "every public building and every school house shall be ventilated in such a proper manner that the air shall not become so exhausted as to become injurious to the health of the persons present therein," and directed that this should be enforced by the

* See *The Engineering Record*, April 9, 1892.

inspection department of the district police force. The annual reports of the chief of the Massachusetts district police published since that date contain some interesting information with regard to the

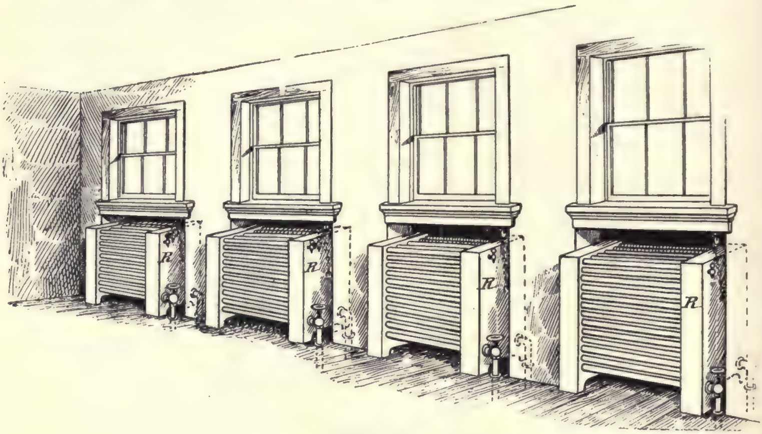


FIG. 175.

ventilation of the school houses of the State, with numerous plans and pictures of school houses, some apparently furnished by the proprietors of patent systems as a sort of advertisement.

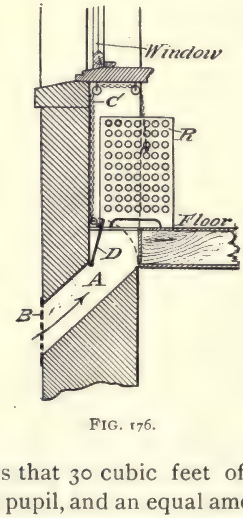


FIG. 176.

"The State requires that 30 cubic feet of properly warmed fresh air be supplied for each pupil, and an equal amount of foul air removed

from the school room per minute, without subjecting the pupils to objectionable draughts; that the temperature be maintained at 70 degrees during the coldest weather, and not vary more than 2 degrees at any point in the room at the level of the breathing line of the pupils. The carbonic acid test should not give more than 8 parts in 10,000 of air." *

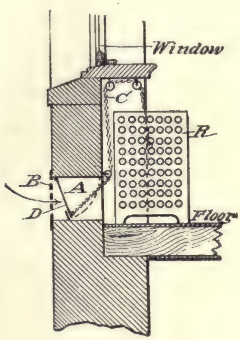


FIG. 177.

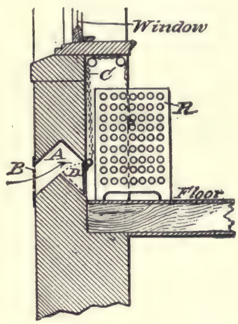


FIG. 178.

The general effect of the law has been good, although the standard of requirement has not been generally attained to, as is shown by the detailed reports of the inspectors.

* Rept. Chief of Mass. Dist. Police, 1892, p. 145.

CHAPTER XIX.

DWELLINGS.

IN the majority of the dwelling houses in this country no special arrangements for ventilation exist. In isolated dwellings, inhabited each by a single family, and having a large area of external surface in proportion to cubic contents, including all farm houses, suburban villas, and the majority of houses in villages and small towns, the problem is one rather of satisfactory heating than of ventilation, for the arrangements for the latter may be very simple.

Let us take as an example a suburban residence such as the architects in our northern cities are often called upon to design, a building which is to be placed on an elevated site for the sake of the view, and which is therefore exposed freely to the cold winds of winter.

The range of external temperature will in this case be from zero to 100° F., and the prevailing winds from the southwest in summer, and from the northeast and northwest in winter, when they may be strong and persistent for several days, with the temperature below the freezing point.

The external surface of the house will be broken by projecting bays, giving it a greater extent in proportion to the cubic space to be warmed than is usual, while the rooms facing the cold, north winds, present special difficulties, so far as securing a comfortable temperature at all times is concerned.

In such a building it will be true economy to use some form of central heating apparatus. Neither fireplaces nor stoves merit consideration as the principal means of heating. No form of hot-air furnace is advisable under the circumstances; it would, in fact, require several furnaces if this form of heating is to be employed; either a hot-water or a low-pressure steam apparatus should be used. The fireplaces in each room will provide ample ventilation for the probable number of occupants, and this ventilation in cold weather is certain to be secured by the amount of fresh warm air which must be introduced to maintain a comfortable temperature. The most important question

to be decided in this case is as to whether the radiators and hot-air flues shall be concentrated into one or two groups near the center of the building, or whether they shall be placed against and in the outer walls.

The difference in cost between these two plans would be about 25 per cent. in favor of the latter, or centralized method. The absolute cost in either case will depend upon whether the amount of radiating surface is to be sufficient to make the house thoroughly comfortable in the coldest weather and during cold northeast storms, or whether such surface is to be calculated only for temperatures about the freezing point, that is, for the average demand, relying upon the fireplaces and grates as auxiliary sources of heat on those days when the apparatus in the cellar is insufficient. If the latter alternative be adopted, the cost of the apparatus can be reduced very much, yet to do so will be a doubtful economy.

The general principle of centralizing the heating apparatus is that adopted by Drs. Drysdale and Hayward in the plans which they give in their book on "Health and Comfort in House Building." After stating that no direct admission of the external air into the rooms of a house can be borne during at least eight months of the year, and that no plan of ventilation, applicable only to single rooms, can supersede the necessity of a general plan for the whole house, they say, that to prevent waste of heat "care should be taken in the original plan of the house to have a central hall, corridor, lobby, fresh-air chamber, or vestibule, separate from the stairs lobby, and into which no outer door should open. The back door should open into the scullery or kitchen, or some other room in which it is to the interest of the servants, for their own comfort, to keep shut. The front door should open into a lobby or vestibule to which there is a separate access from the servants' apartments, without their going through the central hall of the house proper."

From this central hall, kept permanently warm and serving as a warm-air distributing chamber, they direct that the doors of all rooms should open, and they bring the air from this hall into the several rooms near the top of the room through the cornice. The plans of houses given in this work will be found interesting and suggestive.

The removal of the foul air in these houses is effected by the waste heat of the kitchen fire, the air passing from each room at the ceiling to a foul-air chamber, and thence down and behind the kitchen chimney fire, from which point it passes up the chimney.

Within the last 10 years hot-water systems of heating for houses of this class are becoming more and more popular in the Northern

States. A good example of this kind of work is the residence of Prof. W. M. Sloane, in Princeton, N. J., the heating apparatus of which is described and figured in *The Engineering Record* of April 25, 1891.

Figure 179 shows the arrangement in the cellar of the apparatus which was put in to replace a furnace.

A is a Gurney boiler, No. 131, with 804 square inches grate area. *F F*, etc., are flow, and *R R*, etc., are 2-inch return pipes to the direct radiators; *f* and *r* are 2-inch flow and return pipes to the Gold radiators in the stacks *B C D* and *E* which deliver fresh air to lower floor

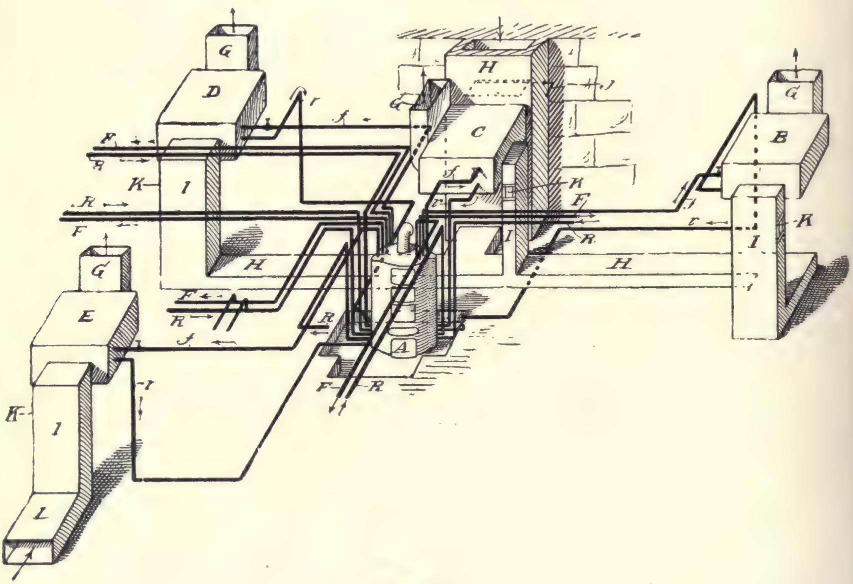


FIG. 179.

rooms through registers at *G G*, etc. Stack *B* is for the reception and sitting rooms; *C* for the hall, and *D* and *E* for the drawing room. *H* is the main fresh-air duct, supplied through a screen and sieve in a large window. *I I I* are branches to the stacks, and *J* and *K K*, etc., are dampers; the former admitting outside air, and the latter, tempered air from the basement. *L* is an independent fresh-air duct from another window. All the air ducts are made of matched pine boards.

The direct radiators are of the Bartlett & Hayward and Perfection type, except a large wall coil in the children's attic play room.

Figure 180 shows the position of the radiator *R* in the library, where it is set between the bookcases and is inclosed by a brass screen *S*.

Figure 181 is a cross-section of Fig. 180 and shows the polished metal lining *T* that is intended to reflect the heat into the room. *D* is a small door commanding the valves.

Figure 182 shows the wooden base *B*, devised to inclose the flow pipe to one of the chamber radiators, where it was necessary to connect with riser *C* and avoid running under the floor. The piece *B* was fitted into the corner of the room and allowed the carpet to come to its outer edges without cutting around the pipe.

The total radiating surface, exclusive of the mains, is about 1,562 square feet.

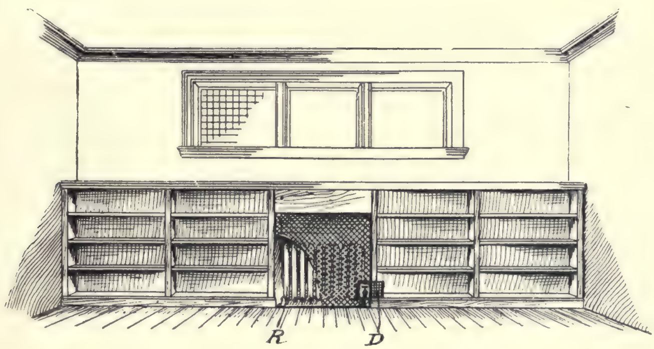


FIG. 180.

Another example of good work in a house of this kind, in which more than usual attention has been given to ventilation, is the residence of Mr. C. S. Onderdonk, at Wyncote, Pa., of which the following description and plans are taken from *The Engineering Record* of July 23, 1892:

The system is one of indirect hot-water, with ventilation of every room into a central stack 25 inches in diameter in the clear, the draught in which is induced by a 10-inch smoke pipe from the boiler. All rooms in the front part of the house are connected to this central stack either directly where it passes through such rooms or adjacent to them, or by means of flues, which are located in the partitions, proceed to the cellar and are then led by means of horizontal ducts into the base of the stack.

The kitchen or frame part of the building receives its ventilation by means of a brick stack *J*, Fig. 183, 18 inches in the clear in which an 8-inch cast-iron pipe is placed which induces the ventilation in that stack. An opening is made immediately over the kitchen range and one at the ceiling of the kitchen, and the rooms above the kitchen are ventilated into this stack.

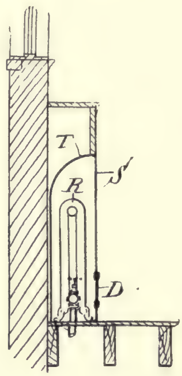


FIG. 181.

A B C D E F G and *I* are down-take flues exhausting the foul air from the owner's bedroom, parlor, sitting-room, den, etc. The water closet on the second floor is ventilated by means of a duct containing 12 square inches of area, which rises from the adjacent partition, and is connected to the central ventilating stack, a connection also

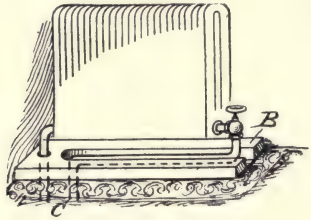


FIG. 182.

being made to the kitchen stack for use in the summer months when the main ventilating stack is not heated. The pipe in the main flue is 10 inches in diameter.

The valves on the flow pipes to each radiator stack are automatically controlled by a Johnson electric thermostat in the rooms respect-

ively served by them. The radiators have no air valves, but are fitted with an air pipe connected to an open riser extending in the main ventilating stack to above the level of the expansion tank. All registers for the admission of warm air to the rooms are located 6 inches below the ceiling, and those for ventilation are set on the opposite side of the room just above the wash board. Each stack of radiators is controlled in addition on both flow and return by Pratt & Cady brass gate valves.

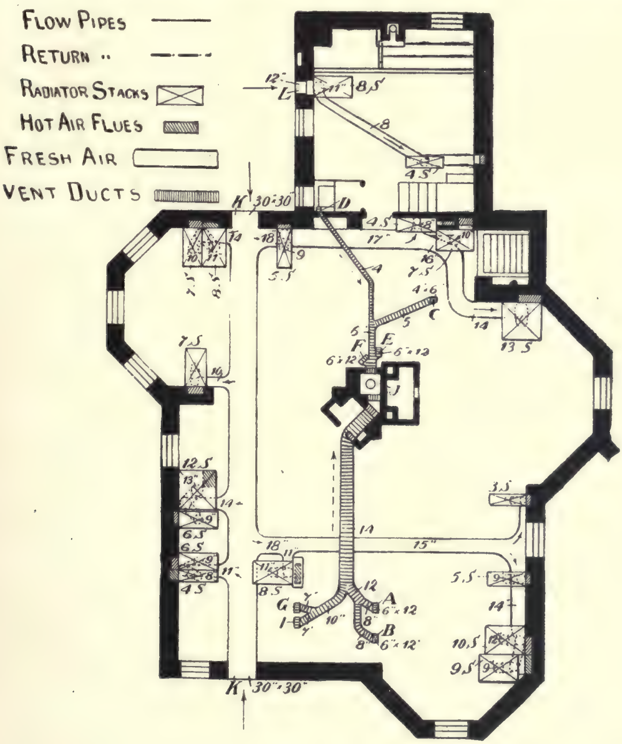
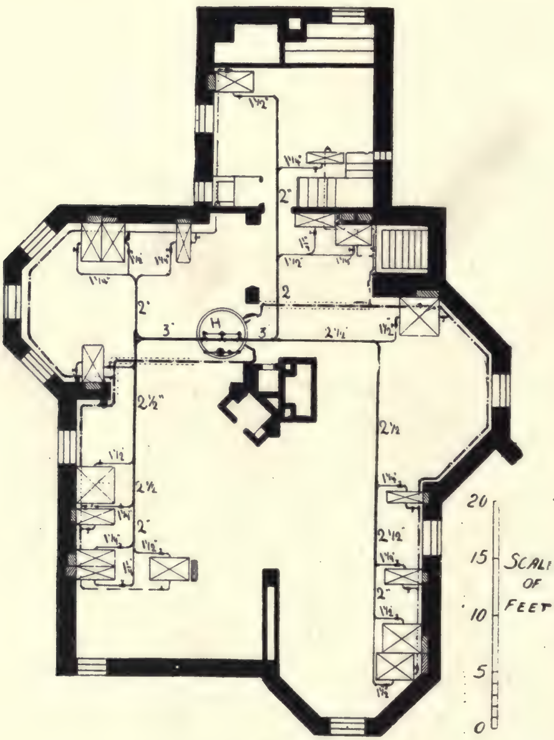


FIG. 183.

The whole system of piping is covered with magnesia sectional covering. In addition thereto the water in the boiler is prevented from reaching the boiling point by means of a Powers limiting device which closes off the draught just before the water reaches the boiling point. The water closet in the laundry in basement is ventilated into the kitchen stack. The galvanized-iron flues for heating when erected

were thoroughly wrapped with asbestos paper, the openings in the wall being thoroughly parged for the reception of the flue.

Fresh cold air is admitted from out doors through windows *K K* and *L*, the two former of which are opposite each other, and are so arranged on opposite sides of the house that either one may be closed and the supply be drawn through the other one according to conditions of sunshine, shadow and prevailing winds. The branches from the



184.

supply ducts to the radiator stacks underneath the latter and so hidden by them, are here shown dotted.

In Figs. 185 and 186, the plans of the first and second floors, the fresh and foul-air flues are marked *M N* and *H*, respectively, to indicate which floors they serve. All registers are marked *R*, with the size.

The system has been in operation an entire winter, and has proved satisfactory.

Figures 187, 188, 189, 190 and 191 show plans of the residence of Gen. A. C. McClurg, in Chicago, illustrating the system of hot-water heating put in by the L. H. Prentice Company, of that city, to which I am indebted for the plans and for the following description.

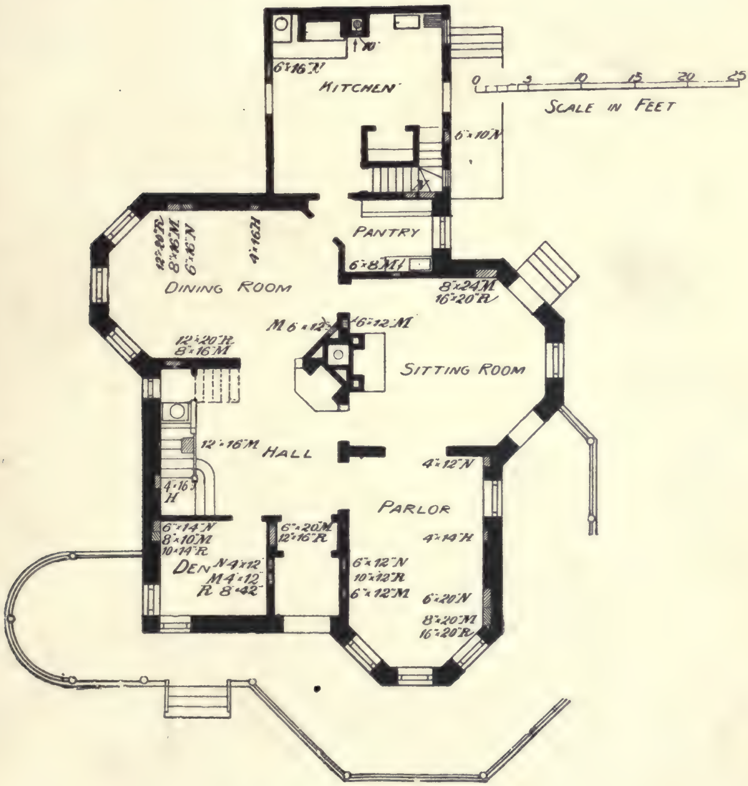


FIG. 185.

The apparatus is a low-temperature open-tank hot-water heating system, designed to accomplish its work with a water temperature not exceeding 180 degrees. The method of heating is by indirect radiation in the principal rooms and halls of the dwelling, the minor rooms being warmed by direct radiation.

Special horizontal wrought-iron tube radiators are used for the indirect surfaces, and the usual ornamental cast-iron vertical loop radiators are used for the direct radiation—the amount of surface in superficial square feet being indicated on each plan. The indirect radiators are enclosed in chambers of brick, connected with a system

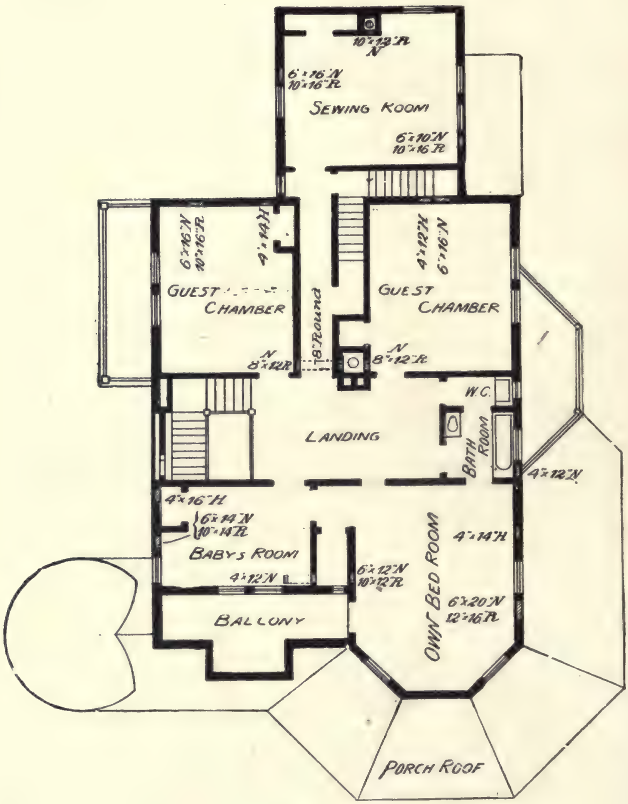


FIG. 186.

of underground air ducts, as shown on the subcellar plan. Before the air is introduced into the ducts, it is first admitted into outside settling chambers, for the purpose of depositing the dust, etc. There are two air inlets, each of which is controlled by an automatic damper, operated by a device which expands and contracts according to the heat of the

water, so that if the circulation is at any time stopped, the danger of freezing is reduced to a minimum.

The underground ducts are built of brick, laid in Portland cement, the top being covered with stone slabs. Provision is also made for taking the air from within the building at such times as the house is not occupied. This also permits of access to the ducts, all of which are large enough to admit the body of a boy or man.

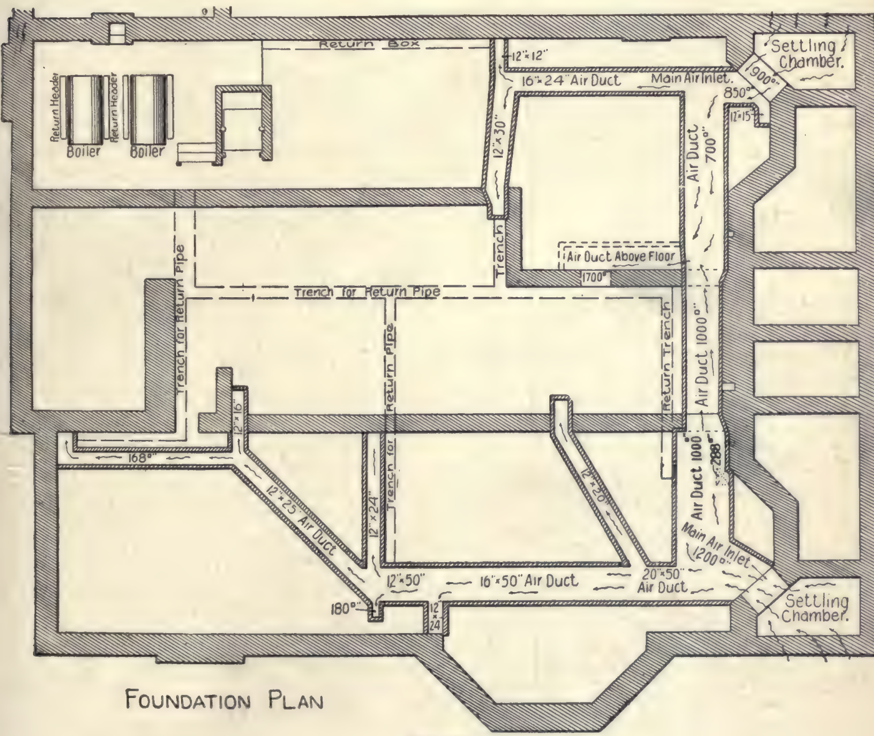


FIG. 187.

Fireplaces are relied upon for ventilation in this house, except in the laundry and in the second-story boudoir, which are ventilated by independent tin flues, which find their termination above the roof of the building in appropriate ventilating cowls or caps. All of the fire-place chimneys are high above the rest of the building, and efficient draught is thus assured.

The subcellar plan indicates the location of the various ducts, and also shows trenches in which the return pipes are run back to boiler. The basement plan shows the location of the various flow pipes, boilers and indirect radiators. The first, second and third-floor plans show the location of the various registers and radiators, also ventilating openings. The return pipes are not shown, as they are identical

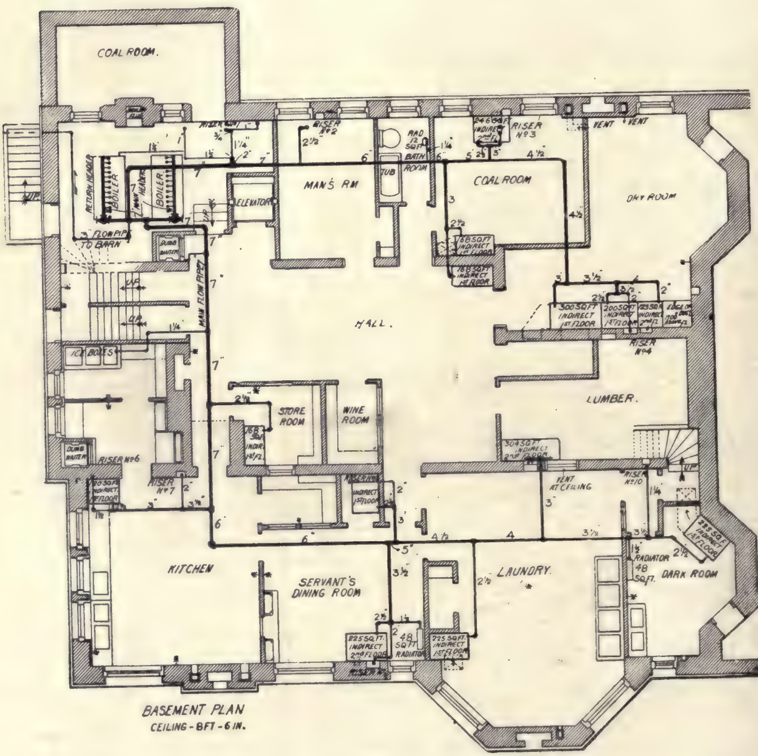


FIG. 188.

with the flow pipes, except, of course, that they are under the floor instead of at the ceiling. All risers and radiators are properly valved for shutting off in case of repairs or changes.

There are two boilers used in this work, being two 12-section Richmond boilers, having 18 square feet of grate surface, and about 500 square feet of heating surface.

The heating apparatus is also operated in connection with the Johnson electric service, which controls the dampers on the boilers, and also individually regulates the temperature of the several rooms, thus correcting any slight discrepancies in the adjustments of the various parts of the heating system.

Figures 192–195 illustrate the system of hot-water heating employed in the residence of Mr. W. A. Fuller, of Chicago, by the L. H.

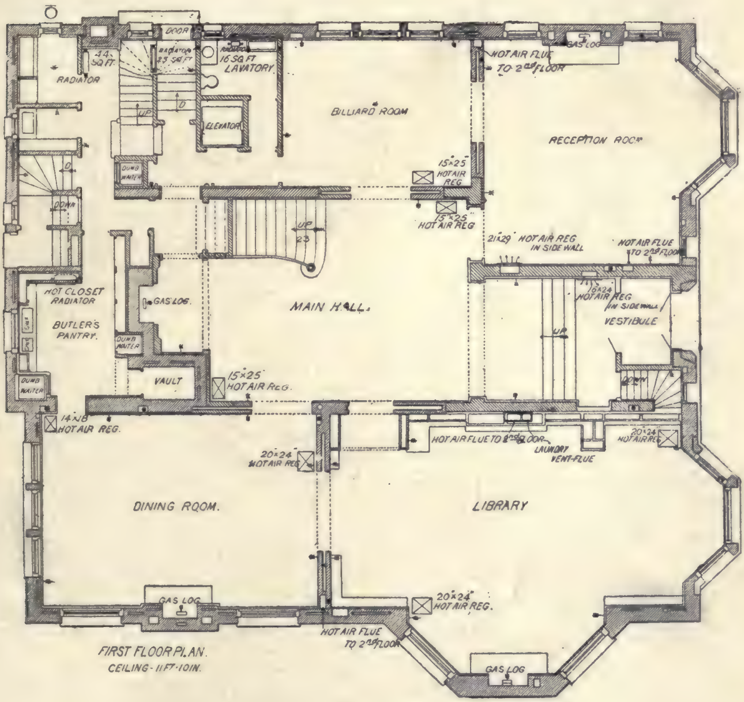


FIG. 189.

Prentice Company, to which I am indebted for these plans. The plans are self-explanatory. The foul air is removed from the living rooms by fireplaces.

Let us now take, as a contrast to buildings of this kind, in which the heating is the most difficult part of the problem, a private residence of the better class, situated in a block in one of our large cities. Such a house will not be exposed to cold, bleak winds, and is in the

most favorable conditions for heating, being exposed to the external air on two sides only.

On the other hand, its ventilation will be more likely to be unsatisfactory, and will require more attention than will that of the country house.

The external air is not as pure; it contains dust of all kinds—soot, street sweepings, etc.; the air in the house is liable to special

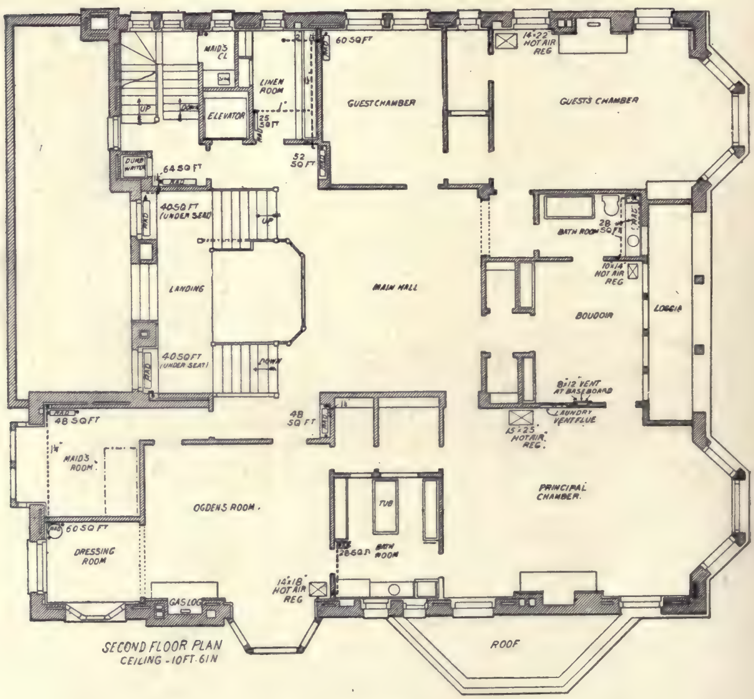


FIG. 190.

contaminations by leakage of gas into its cellar or basement; and it has happened that offensive gases have passed directly through party walls from one dwelling to another. The great cost of the ground leads to gaining space by increase in height, while every additional story adds to the cost and difficulty of providing equable and satisfactory heating and ventilation.

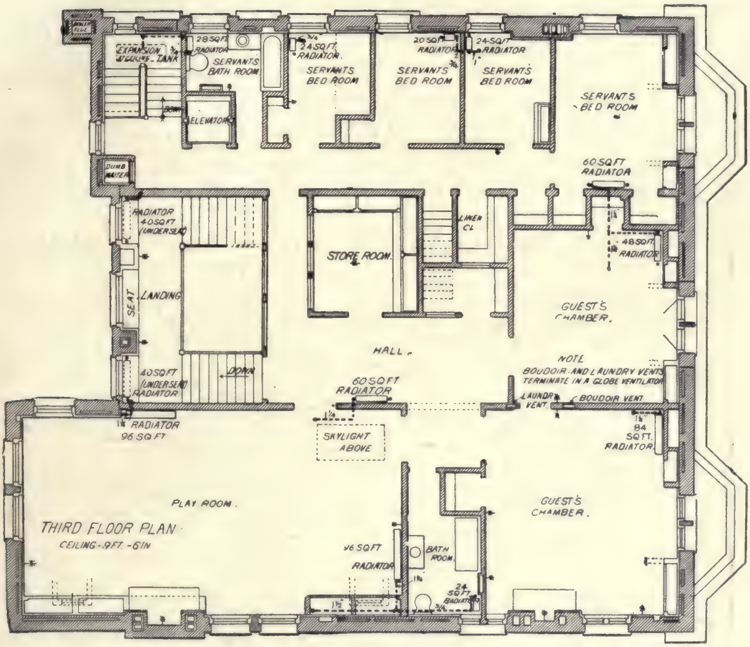


FIG. 191.

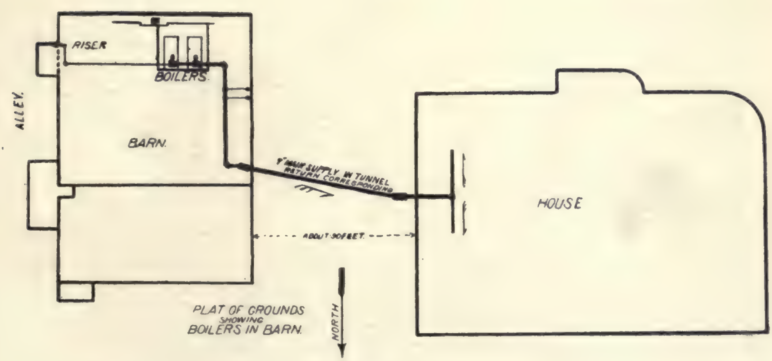


FIG. 192.

In a tall building, where all the rooms open directly into the staircase hall, and no provision is made for dividing this hall and staircase upon the several stories, so as to prevent the free communication of the air

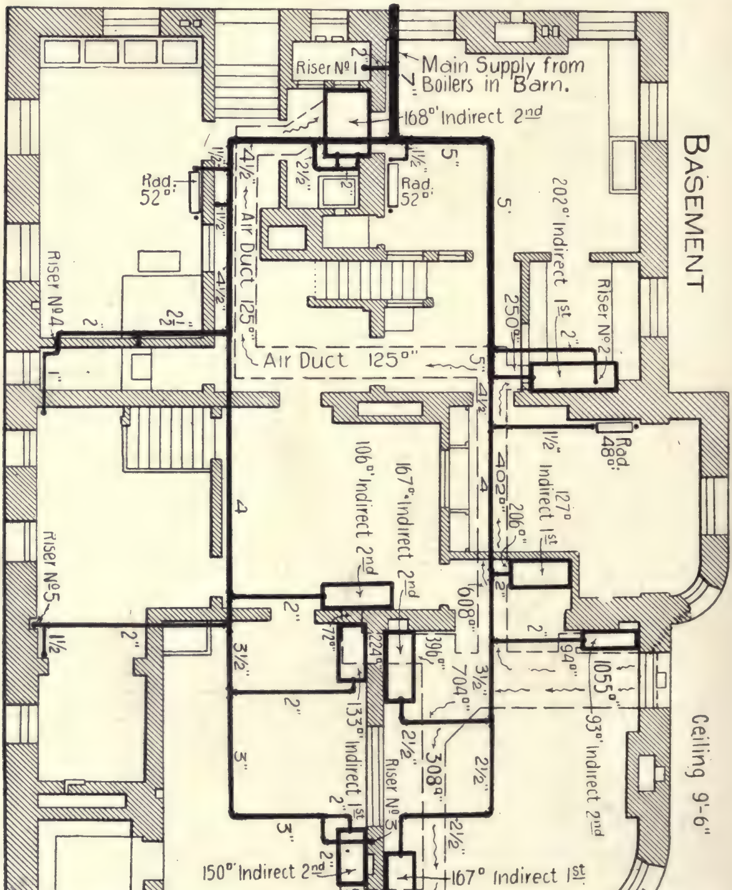


FIG. 193.

in it, the result is that the hall is liable, by leakage from above, or by the opening of a window in the upper story, to become a ventilating shaft, which will interfere with the proper working of the chimney or

ventilating flues within the rooms. In such buildings, in cold weather, it will often be found that the upper stories have a temperature several

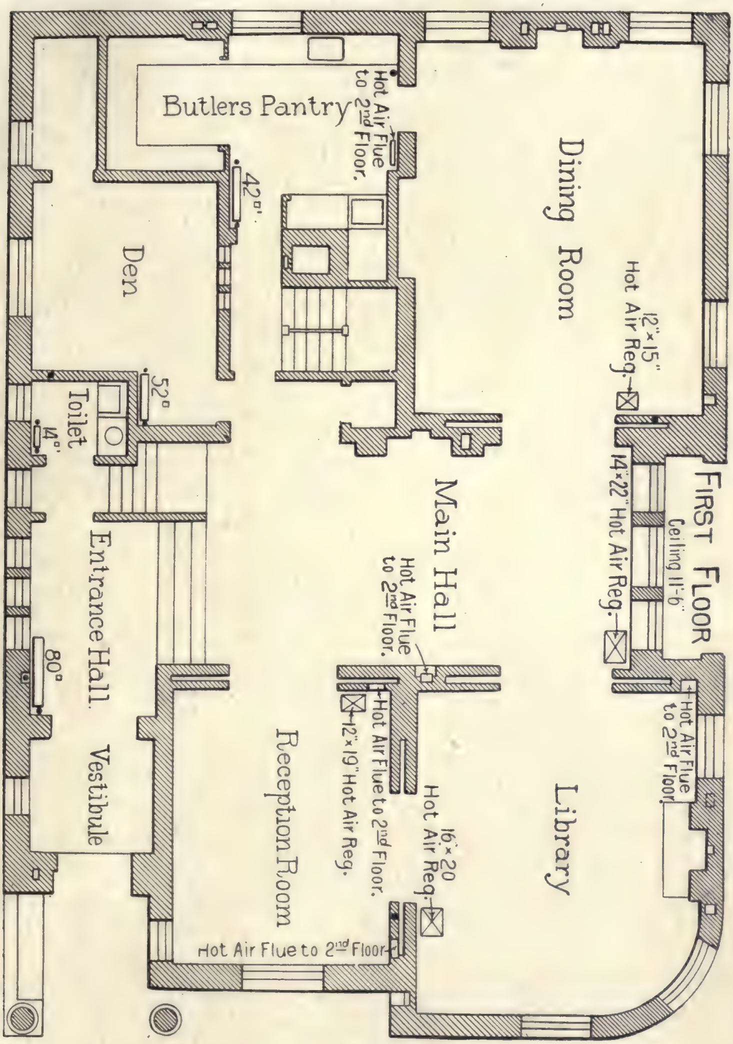


FIG. 194.

degrees higher than the lower, and, if the house be heated by indirect radiation, that to secure comfort in the parlor and dining room, the bed-

rooms are made too hot. It is especially difficult in such houses to prevent the odors and steam from the kitchen and laundry, which are usually placed in the basement, from being unpleasantly perceptible in the halls and upper stories.

On the other hand, both the fresh and the foul-air flues will be, for the most part, on inner walls, where their operation is not liable to be interfered with by winds or cold.

One method of arranging such a city dwelling is shown in the accompanying illustration (Fig. 196). The plans of the first and

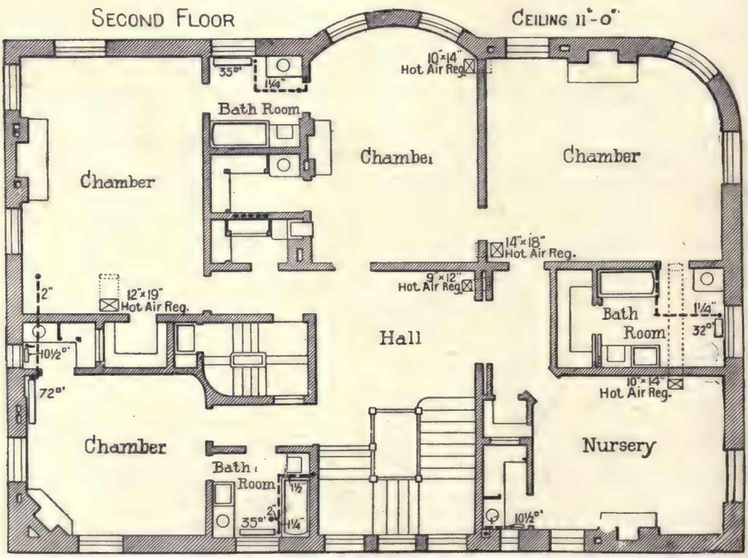


FIG. 195.

fourth floors are not given, as they are not necessary to an understanding of the system of heating.

The essential feature of this house is the central hall, occupying the whole width of the building, and well lighted from above by a large skylight.

It will be seen that a part of this hall is cut off for a private or back staircase and a lift, and that upon the parlor and upper floors it forms a part of the main suite of rooms. At the skylight is an opening having an area of 2½ square feet, always open, and when the heating apparatus is in operation there is a steady upward current

from the basement through the staircase well, which is just perceptible to the hand, being between 1 and 2 feet per second.

The plans are, for the most part, self-explanatory.

The heating is by steam at a very low pressure, the boiler being entirely out of the house under the front pavement. The heating coils are divided into three groups, as shown in basement plan, having in all about 2,200 feet of 1-inch pipe. Before reaching the coils the incom-

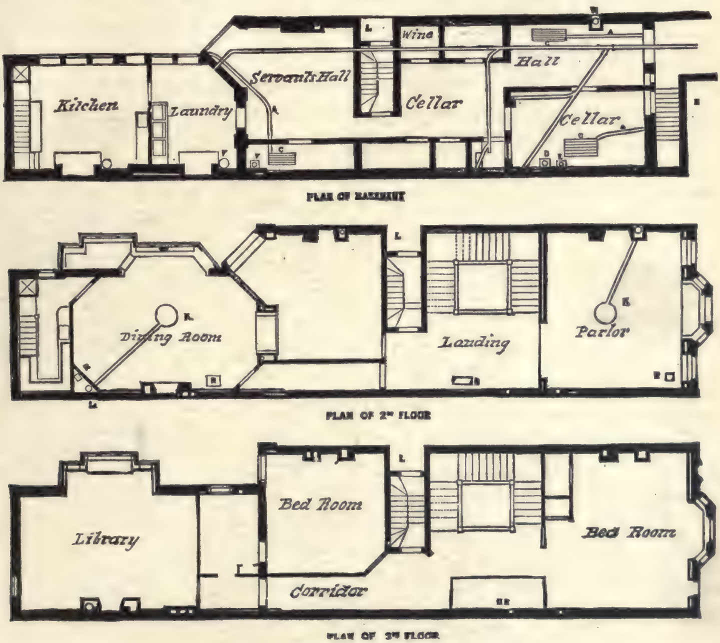


FIG 196.—DESCRIPTION OF PLANS.

A.—Fresh-air inlet flues.
B.—Boiler, separated from house by open area.
C.—Heating coils.
D.—Flue to hall and second story.
E.—Flue to third-story bedroom.
F.—Flue to dining room.
K.—Chandelier with vent to convey products of gas combustion.
L.—Kitchen heated flue.
H.—Chimney of boilers with cast-iron flue into which gas lights are ventilated.
R.—Registers
B R.—Bathroom.

ing air is filtered by being drawn through sheets of cotton wadding placed between wire frames. The results are stated to be extremely satisfactory. The greater part of the ventilation is effected by the central hall and skylight. The amount of air supply is very large, and no difficulty has been experienced in having open fires in open fireplaces when desired. The chandeliers in the parlor and dining room contribute

to the ventilation, as shown on the plans, and it is stated that 20 persons can smoke in the dining room without causing the least accumulation of smoke. Similar ventilation is supplied to the chandeliers in the library and other rooms upon the third floor.

Of course the flues with which these chandeliers communicate must pull against the great central staircase flue, but the results reported are so satisfactory that it is evident that the amount of air supply is so large as to be ample for all the outlets. The amount of fuel used must be relatively large—that is, large as compared with what would be required to heat the same house with the same apparatus if only the ordinary amount of ventilation were provided.

Figure 197 is a plan of another city house in a block. This is the common arrangement in such rows of dwellings, the characteristic feature being a narrow, rather dark hall extending from front to rear, on one side of the building. This hall contains the stairway, and in many cases a water closet. The annexed illustration gives the main floor plan of such a residence, which is superior to the average in size.

This house is heated by two furnaces, the locations of which are shown in dotted outline and this mode of heating will prove entirely satisfactory, provided only that the fresh-air ducts and the heating surfaces are made large enough to prevent the possibility of the air as it leaves these surfaces having a higher temperature than 140° F.

The best way to arrange the ventilation of such a house as this would be upon the principles indicated by Drysdale and Haywood, and for this purpose more space should be given in connection with the kitchen chimney.

With fireplaces and separate flues therefrom in all living rooms, there will be little trouble about ventilation at all times, when the external temperature is below 40° F., for there will then be a steady current up each flue, provided the fresh-air supply be sufficient, which last must be the case if the room is satisfactorily warmed. The special difficulty in ventilation in a house like this, and one of the chief dangers to health, is due to the pollution of the air of the hall and sleeping rooms from the plumbing arrangements.

With a dark water closet near the center of the house, it is necessary to take special precautions to secure its satisfactory condition at all times. The methods of doing this, so far as plumbing work is concerned, do not fall within the scope of this work, but I must insist upon the necessity of a satisfactory ventilation of the closet itself. The surest mode of effecting this is by a shaft passing up and through the roof and suitably capped, as I shall hereafter explain, in which shaft a

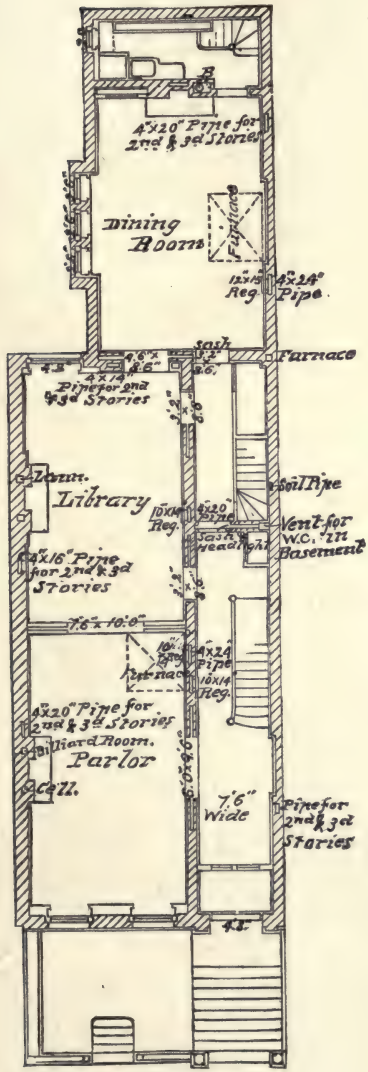

4"x20" Pipe for 2nd & 3d Stories
Dining Room
Furnace
12x15 Reg.
4"x24" Pipe
Sash
Furnace
4.6"x 8.6"
4x14 Pipe for 2nd & 3d Stories
Library
Soil Pipe
10x14 Reg.
4"x20" Pipe
Vent for W.C. in Basement
Sash Headlight
4"x16" Pipe for 2nd & 3d Stories
7.6 x 10.0"
4x24 Pipe
10x14 Reg.
Furnace
4"x20" Pipe for 2nd & 3d Stories
Billiard Room.
Parlor
7'6" Wide
Pipe for 2nd & 3d Stories

FIG. 197.

steady aspirating force is to be exerted by means of a gas jet, which may at the same time serve to light the closet.

This shaft should take its air supply from beneath the seat of the closet, and it will be well to place in it the soil pipe, which I take for granted is also to be continued up through the roof.

The area of this ventilating shaft should be about 30 square inches, if it passes straight up without bends or corners and does not contain the soil pipe. The portion of the flue within the closet can be best constructed of galvanized iron, and should be fitted as a lantern at the point where the gas jet is brought into it. This gas jet should have a stop so arranged that it can never be turned entirely out without the use of tools, although it may be reduced to a very small flame.

The warmer the weather, especially if it is still, the more heat will be needed from the jet to secure satisfactory ventilation. The air supply for the closet should be taken from the hall through a transom or louvered openings in the top of the door, thus making the closet the bottom of an air shaft for ventilating the hall.

I wish it to be clearly understood that the arrangement is recommended only for those houses which have their drainage properly arranged, and where the closet is not against an outside wall. The use of the gas jet is advised, because it is, upon the whole, the cheapest method of securing a constant upward current under such circumstances. There are various ways of arranging the gas jet, some of which are patented, but these do not seem to me to require special comment.

Even in houses having special provisions for ventilation, the closets for clothing are usually not arranged for any circulation of air. This should be provided for by openings at the floor and near the ceiling, which openings may be covered by cotton batting or cheese cloth filtering frames if the housekeeper objects to simple openings on the ground of their giving ingress to moths. Soiled clothing or bedding, or bags containing them, should not be placed in any closet.

Figure 198 is a basement plan of the house of Mr. S. L. George, at Watertown, N. Y., showing flow and return mains of the system of hot-water heating, the full lines indicating flow and the broken ones the returns. The parlor, drawing room and main hall are heated by indirect radiation, the rest of the house by direct radiators and by fireplaces which act as outlets. The riser flow lines to direct radiators are indicated by full oblique lines at *A B C D* and *E*. At *F G* and *H* are connections to first-floor radiators. The direct radiators at the different risers have total surfaces for their respective cubic feet of

space heated as follows: At *A* is a tower room having 1,287 cubic feet air space, with an exposure to the west. It has 3½ square feet radiating surface per 100 cubic feet air space. At *B* is a chamber having 2,376 cubic feet air space, with northern and eastern exposures. It has

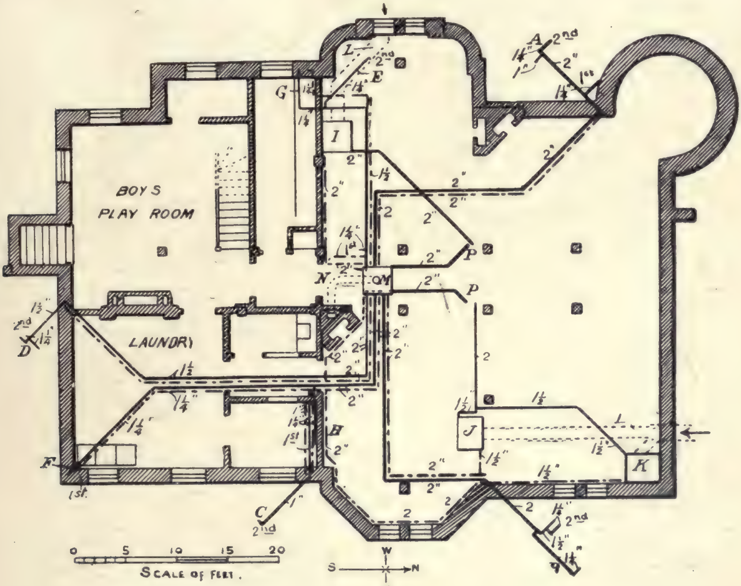


FIG. 198.

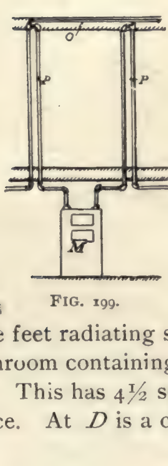


FIG. 199.

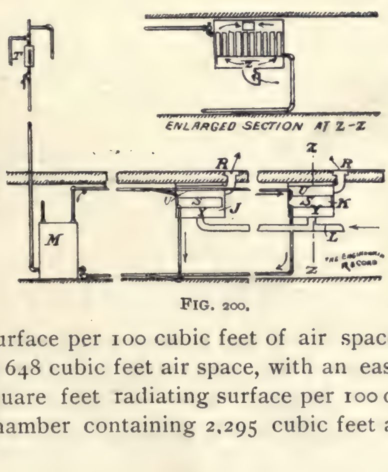


FIG. 200.

3 square feet radiating surface per 100 cubic feet of air space. At *C* is a bathroom containing 648 cubic feet air space, with an eastern exposure. This has 4½ square feet radiating surface per 100 cubic feet air space. At *D* is a chamber containing 2,295 cubic feet air space,

having a southern and western exposure, with 2½ square feet radiating surface to 100 cubic feet air space. At *E* is a chamber having 1,872 cubic feet air space, with exposure to the west, north and south, with 3 square feet radiating surface per 100 cubic feet air space. At *F* is a bathroom containing 680 cubic feet air space, having exposures to the south and east. It has 4½ square feet radiating surface per 100 cubic feet air space. At *G* is a butler's pantry containing 700 cubic feet air space, with a western exposure. It has 4½ square feet radiating surface per 100 cubic feet air space. At *H* is a chamber having 2,560 cubic feet air space, with an exposure to the east, and 3 square feet radiating surface to 100 cubic feet air space.

I J and *K* are indirect radiator stacks, each of 150 square feet of surface to warm about 2,975 total cubic feet of air; *L L* are fresh-air conduits; *M* is a Richardson & Boynton Company No. 28 "Perfect" boiler, with 676 square inches of grate area; *N* is the smoke flue; *P P* are syphons intended to promote the circulation in the indirect stacks.

Figure 199 shows the arrangement of syphons *P P*; *O* is a vent pipe to the expansion tank. Figure 200 shows the arrangement of indirect stacks *J* and *K*, and expansion tank *T*. Cold air is received from duct *L* in the cold chambers *Q*, and passing through the extended surface radiators *S*, passes into the hot chamber *U*, and is thence delivered through the floor radiator *R*.*

Figures 201–203 show the hot-water heating apparatus in the house of Mr. W. H. Carrick, of Toronto, Canada, which is typical of the system of piping largely followed in Upper and Lower Canada in the warming of buildings by hot-water circulations.

The plant has proved ample for the warming of a fairly well built wooden structure with water ranging from 120° to 190° F., according to the state and requirements of the weather outside.

It will be noted that the cubic contents of rooms are marked, the position of heaters shown, and their sizes marked, the figure attached to each indicating the number of "Bundy" loops, each loop being nominally 3½ square feet of heating surface in the hot-water radiator.

The heights in the clear of floors are, for the principal or *first* floor, 10 feet 6 inches; the *second* floor, 9 feet, and the *third* floor, or attic, 8 feet.

The sizes of the mains and floor pipes are marked on the plans, and the boiler is a No. 25 Gurney; the consumption of anthracite coal

* From *The Engineering Record*, November 21, 1891.

for a season being seven tons and just about 100 pounds per day in cold weather; the climate of Toronto differing very little from the cities of northern New York, Ohio, Michigan, western Pennsylvania and the Eastern States. This, then, may be taken somewhat as a guide to the plant and its maintenance for a $5,000 house on a 20-foot city lot in the new district of New York or in Brooklyn.

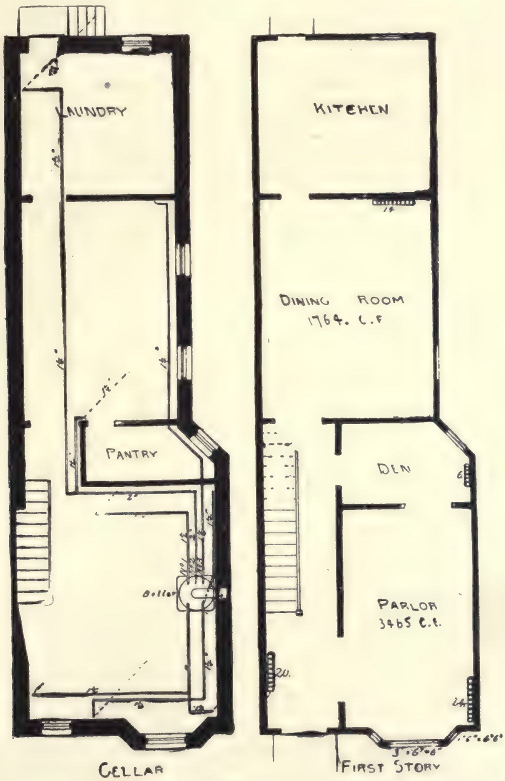


FIG. 201.

Figure 203 shows the skeleton apparatus, and a reference to the plans will show its relation to the house. The boiler is in the front cellar. The radiators marked *A* in the diagram are on the principal floor, those marked *B* are on the second floor, and the ones marked *C* are on the top floor.

The circuit No. 1 starts from the boiler $1\frac{1}{2}$ inches in diameter, runs along with the rest of the pipes to near the pantry, where it turns upward and runs through the partition to the top floor, where it comes out and branches to the two radiators and expansion tank.

Circuit No. 2 starts from the boiler 2 inches, and continues on to the end of pantry where it has a tee $2'' \times 1\frac{1}{4}'' \times 1\frac{1}{4}''$; one branch of which

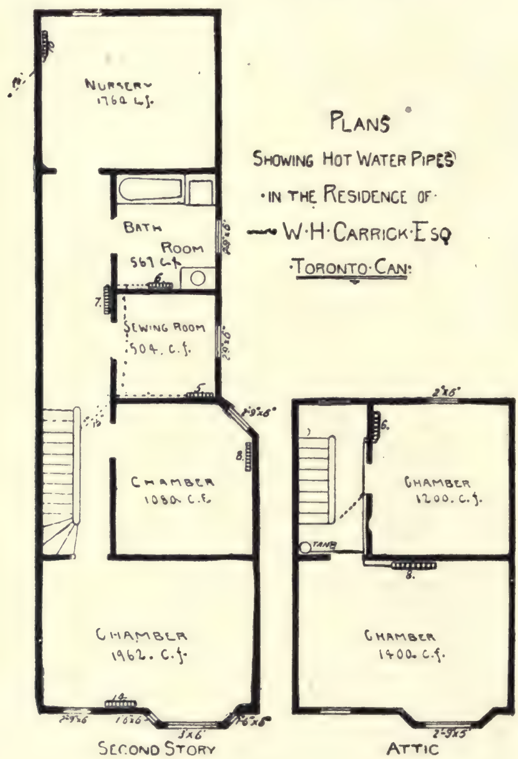


FIG. 202.

goes along parallel with side of pantry to pantry door and then goes up through the partition and feeds sewing room, bathroom, and upstairs hall. The other branch runs straight to the back end of house, and up through the kitchen to the nursery, where it heats the radiator near the window. It may seem strange that this break was made in this way, but it was found when split at the point where the first pipe went up that the circulation was very sluggish, and that

the nursery radiator did not heat properly, hence the change of running the two pipes parallel to this point.

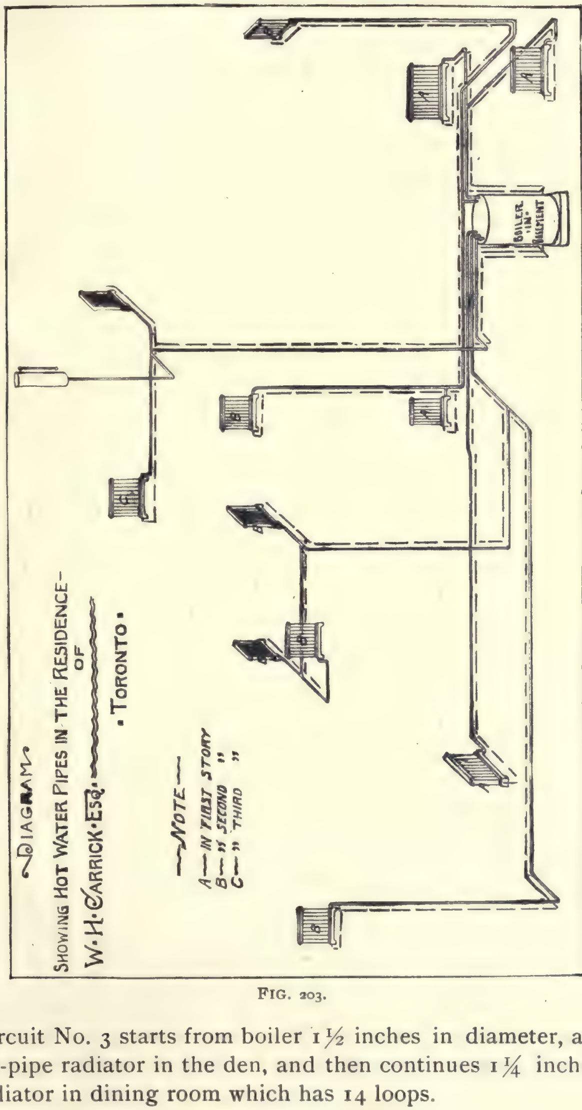


FIG. 203.

Circuit No. 3 starts from boiler 1½ inches in diameter, and heats the six-pipe radiator in the den, and then continues 1¼ inches on to one radiator in dining room which has 14 loops.

Circuit No. 4 starts from boiler 2 inches in diameter, and branches to a 1½-inch pipe to the lower hall, and 1¼ inches to parlor.

Circuit No. 5 breaks at the boiler into two 1¼-inch pipes, one going to front chamber where it heats the 14 loops, and the other to the back chamber (second floor), where it heats the eight loops.

The flow and return pipes of a circuit are exactly alike in size and almost identical in the manner of being run. The pipes are near the ceiling, with a pitch of about 1 inch in 10 feet.

Each radiator has an angle valve on the inlet end and an air cock in the top chamber. Although air collects in this chamber a neglect of a week is not sufficient to affect the flow of the water. The dotted lines in the plan indicate pipes under floor or in partitions, while the dotted lines in the diagram indicate the return flow pipe. The pipes through the cellar are covered with a plastic non-conductor.*

In a recent number of the *Genie Civil* of Paris, M. Somasco describes a house constructed at Creil, France, in accordance with the views of Leeds and of M. Trélat that the walls should be warmed and the fresh air admitted cold.

This house is a separate dwelling of two stories, with large hall and attic. The walls are hollow, having a total thickness of about 22 inches, the exterior wall being about 9 inches, and the interior of 4 inches, with a hollow space of from 8 to 9 inches.

The walls of the basement are solid ; at their upper part near the ceilings, all around the interior, are openings into the hollow wall space ; the interior partition surrounding the basement forms a large passage closed in front of the openings into the hollow walls. This passage is in direct communication with the external air. On all sides of the house are large openings. In the interior of the passage there are heating pipes containing warm water for the purpose of heating the air ; this warm water being circulated in the hollow wall, heats also the whole establishment. The external air is admitted throughout into the different rooms by a natural orifice without any heating, and is taken out by chimneys for each department.

Figure 204 is a plan of the basement and Fig. 205 is a section showing the mode of admission of fresh air through the outer wall and the mode in which the heated air enters the space between the walls above the basement.

The temperature of the air in the interior of the walls varies from 45° to 50° C. ; under these conditions the temperature of the walls on their internal surface is from 30° to 36° C. in the lower story ; to

* The above description is taken from *The Engineering Record.*

the touch the wall gives no sensation of heat, whatever may be the variations of the external temperature. That of the interior surface of the walls never varies more than 6 degrees. The temperature of the wall decreases about 1 degree per meter of height. From above the second story the air passes out into halls at a temperature of 40° C. The location of the house is a damp one, but the interior is dry, and the house is said to be very comfortable. There is never any need for

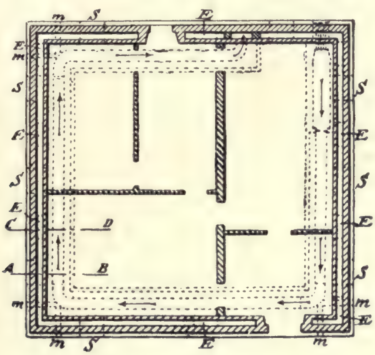


FIG. 204.

supplementary heating in the fireplaces, and the supply of fuel required is said to be small.

In a cold climate however the loss of heat through the outer wall would involve a heavy cost for fuel.

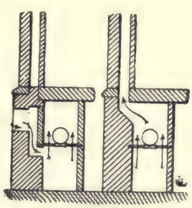


FIG. 205.

In the preceding remarks upon the heating and ventilation of dwelling houses, only such buildings have been kept in view as architects are usually called upon to plan or construct—namely, the larger and better class of city residences and suburban villas.

It has been pointed out that the problem in such houses is comparatively simple; the difficulties relating mainly rather to warming than to ventilation, although it must be confessed that, simple as it is,

it has been in the majority of such houses not only unsolved, but not even supposed to exist. But what shall we say of the houses with which architects have nothing to do, but which contain the immense majority of our people, both in cities and in the country? Taking these as we find them, what should we recommend to their owners or tenants as desirable improvements?

Let us first take an extreme case, such as a room in a tenement house which is occupied by a family of four or five persons. The room, about 14 feet square and 10 feet high, must serve as a kitchen, living room and bedroom. It is heated by a small cooking stove, has one window, and one door opening into an interior hall, which is dark and dirty.

Every pound of fuel is a matter of importance, and every chink and cranny at which cold fresh air might enter is, as far as possible, stopped up. During cold weather, and under ordinary circumstances, it is practically impossible to do much toward improving the ventilation of this room; impossible, not because of mechanical difficulties, but because the occupants do not want ventilation, which will either make the room cold or increase the expense for fuel. Occasionally, however, in case of sickness, the doctor insists on having some fresh air for his patient, and it is well to know what can be done to secure this. Anyone who understands the general principles of ventilation and has a little mechanical ingenuity will find no difficulty in this respect. To secure a fresh-air inlet, for instance, raise the lower sash of the window from 4 to 6 inches, by placing underneath it a piece of board which will just fill the opening thus created. This makes a fresh-air inlet at the point of junction of the lower and upper sashes, and the incoming stream of air will be directed upward, so that it will not usually cause an unpleasant draught.

The same effect can be obtained by removing one of the upper panes in the upper sash and fitting to it a sort of hopper or funnel made of tin or pasteboard, so arranged as to direct the current of air to the ceiling.

The outlet must be obtained by the chimney flue, the simplest plan being to make an opening about 9 inches in diameter into the flue, and so arrange a valve of paper, in a pasteboard tube or bit of stove pipe placed in this opening, that a reverse current will be prevented, being a rough-and-ready application of Arnott's valve. Physicians of the poor, and those engaged in charitable work, as well as all nurses, should be prepared to devise such simple methods as these with little or no cost, and in this connection attention is invited to the essay on

"An Effective and Ready Method of Ventilating Sick Rooms," etc., for which a prize was awarded by the Massachusetts Medical Society to X. Y. Z., in 1871, and which will be found in the papers of that society for 1872.

Care must be taken to make the tubes of sufficient size, for some very absurd ideas have been urged in favor of the use of small pipes. For instance, Dr. George Wyld, one of the Committee on Sanitary Science at the Society of Arts, in a paper presented to the Social Science Association in 1858, says: "I roughly estimate the diameter of the required piping necessary to ventilate any given apartment at about a multiple of the diameter of the trachea or main air passage from the lungs of those present. For instance, to ventilate a room containing generally eight individuals, a pipe about 2 inches in diameter would be sufficient." Upon such teaching as this, it is not to be wondered at that architects and engineers should put a low value, especially as Dr. Wyld relies on his little tube exclusively and makes no provision whatever for the entrance of fresh air.

Passing from the tenement room, let us take the small house of from three to six rooms, occupied by a single family.

Such houses in this country are usually heated by some form of stove, and have no special means of any kind for the inlet of fresh or the exit of foul air. The rooms are small, the hall, if there is one, is not heated, and the bedrooms are warmed only on special occasions, as in case of sickness.

The house will be of brick, with 9-inch walls and plenty of cracks from shrinkage about doors and windows and at the washboards. The amount of air which would enter through these cracks, and directly through the walls of the house were it not in a block, would be nearly enough for ventilation purposes. The permeability of the walls is, however, often destroyed by papering them. To save labor as well as fuel, usually but two fires will be kept up, one in the kitchen and one in the sitting room, and in very many houses of the kind we are speaking of, the kitchen fire is the only one to be found during the greater part of the time.

Economy in fuel and labor is here the first consideration, and to secure these results many different patterns of stoves have been devised, but with regard to the relative merits of these various patterns we have singularly little information. During the last 10 years, however, a number of attempts to secure the introduction of fresh warm air by means of the stove have been made, and there are now on the market several patterns of ventilating stoves devised for this purpose.

So far as economy in fuel and labor is concerned, when anthracite coal is to be used, the most approved modern patterns of base-burning stoves give excellent results if connected with the proper flues, but as usually set up they not only give no aid to ventilation, but often are direct sources of contamination of the air of the room with the gaseous products of combustion. In order to secure the greatest possible utilization of all the heat produced in a stove, it is necessary that the smoke shall pass into the chimney flue at the lowest temperature consistent with securing sufficient and regular draught, and to this end much may be effected by such contrivances as sheet-iron drums, etc., which will utilize the waste heat in warming the room above. The Latrobe heater, so well known in Baltimore and vicinity, is another means of doing the same thing.

The mode of action of a close stove has been clearly and well described by Mr. Briggs: "Surrounding any stove in active operation, there exists an envelope of air gradually ascending, as it acquires heat, toward the ceiling. In what way does this envelope come to have any considerable thickness? Air is nearly a perfect non-conductor of heat; one particle of air does not, or at least very slowly receives heat from another particle. As before stated, air permits the transmission of radiant heat without absorbing it. Only the thinnest film of air can possibly be in contact with the surface of the stove at any instant of time, and yet it is only by contact that the air is heated.

"In fact, the air does not, nor does any fluid, whether gaseous or liquid, slide upon a surface along which it passes. The movement is a rolling one. D'Arcey describes the movement of water in a pipe to be similar (but reversed) to the stripping of a glove from the finger, by turning the glove finger inside out.

"In a similar rolling movement the sheet of air passing the stove comes to have a definite thickness, and involves in its rolling process particles of air remote from the ascending stream.

"As a stone thrown into a pool transmits its vibrations over the surface, so any disturbance of a fluid body confined in an inclosure is transmitted and communicated throughout the fluid to its most distant part, with some relative intensity. There rises from the stove a current of air of considerable volume, acquiring, as it ascends, a nearly uniform temperature, but with a nucleus hotter than the general temperature of the room. This heated air endeavors to find its level next the ceiling, but to do so it must not be assumed to slide in under the warm air which it finds in contact with the ceiling. Instead of this, the interposition will be accomplished by a rolling action similar to that on the

stove surface, wherein one set of particles rolls off and the other rolls upon the ceiling with mutual admixture and equalization of temperature in the process.

"With the accumulating of a stratum of heated air next the ceiling, a corresponding absorption from the floor stratum must have occurred. The necessity for the stove at all is the presumption that some loss of heat must have been going on at the windows and walls equivalent to the heat imparted by the stove.

"The windows and walls impart 'cold' in the same way and after the same laws of convection as the stove imparts heat. In one part of the room the stove will have been forming an ascendiug current of considerable intensity or velocity all around itself, while at another part the windows and cool walls will have a sheet of cool air, of less velocity, but of equal heat-value, traversing them downward.

"The most uniform distribution will be effected when these currents become the most general, extensive, and, consequently, most moderate. Suppose the stove to have its position remote from the windows and cooling walls, and to be so placed that the average extent of window or wall surface or exposure shall be equidistant from the stove; it can then be asserted that the column of hot air from the stove will, after rising, roll upon the ceiling and become intimately mixed and equalized in temperature with the air it finds there, and that the sheet of descending air from the windows and walls will roll out upon the floor and intermix with the air on that level, establishing an equality of temperature in that stratum. Within certain well-known limits of size or shape of room, and with a close room, the lower 6, or 8, or 10 feet of height of the room will be heated by a stove in any weather, so that the differences of temperature within that height shall not affect the comfort of the occupant.

"Where the stove employed is so small as to demand inordinate heating of its surface to impart the required quantity of heat, successful warming is secured by protecting the occupants from direct radiation by screens of inclosing envelopes, which are found to accelerate the rising current of hot air, and this is done without very materially impairing the distribution of heat, and even when the sashes are not very tight in the window frames, tolerable uniformity of ground temperature is reached." *

About one-third of the effect is due to radiant heat and the rest to heat carried by the air which rolls up the heated sides of the stove and pipe. In the best forms of base-burner, with thin castings and

* *The Sanitary Engineer*, September 1, 1880, page 372.

relatively large surfaces of mica near the glowing coals, the proportion of radiant heat is greater than this, amounting to over one-half the total effect.

To arrange an ordinary cylinder or box stove so that it shall warm the fresh air entering the room, the essential thing is to surround it with a jacket of sheet iron or zinc, leaving the necessary opening for access to the stove, and then to connect through an opening in the floor the space between the jacket and the stove with the outer air. The amount of air which will be thus introduced will depend not only

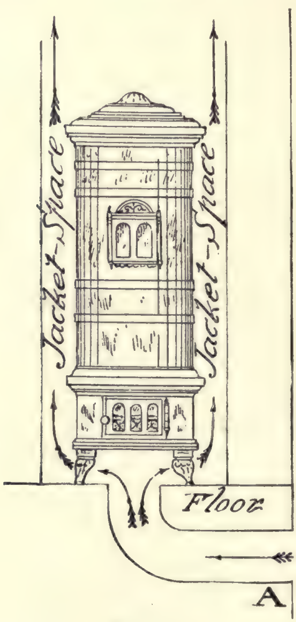


FIG. 206.

on the area of the opening and the difference between thc temperature of the room and that of the open air, but also on the arrangement made to secure exit of air from the room. If the room have a fireplace in it and the stovepipe enters the upper part of the flue coming from this fireplace, which is a very common arrangement, the exit of air can be readily provided for by leaving the fireplace open.

If there be no fireplace, an exit shaft may be carried up by the side of the chimney, from near the floor to near the ceiling where it

enters the flue, and if this exit shaft be so arranged as to receive heat from the upper part of the stovepipe it will work very well.

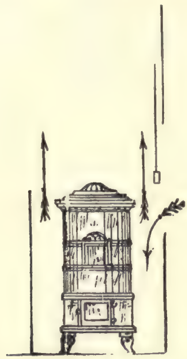


FIG. 207.

Some simple methods of using the common stove for ventilating rooms are described by Dr. D. F. Lincoln in his paper on "School

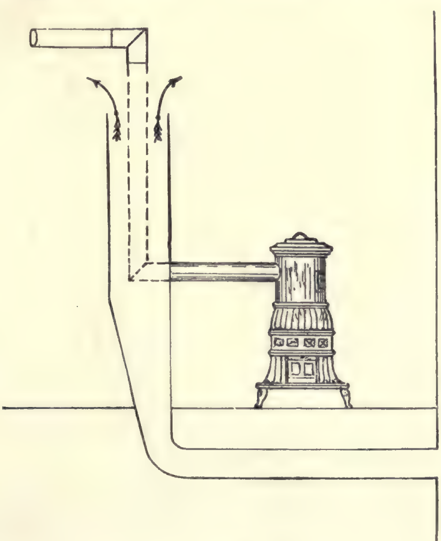


FIG. 208.

Hygiene," printed in the Second Annual Report of the Board of Health of the State of New York for 1881-1882.

"In a variety of ways," Dr. Lincoln says, "the stove or stovepipe can be used to expel air from the room. The 'jacket' or metal screen is a thing of which no stove in an inhabited room should be destitute, as a protection from heat. But it is mentioned here as affording an aid to ventilation. Figure 206 shows how this is done. A metal cylinder, considerably wider than the stove, is placed around the latter, and its edge is fastened to the floor. A good sized pipe is then carried through the floor, under the stove, and led through the house wall at *A*, Fig. 206. Guard the inlet with a screen of wire at *A*, and a large supply of pure warmed air is drawn into the room. This is one of the

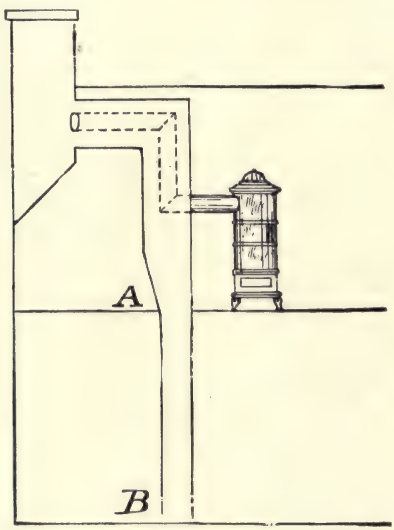


FIG. 209.

cheapest and best devices for warming and ventilating. Some prefer to extend the jacket around only a part of the stove and leave the door uncovered; or the jacket may stop at the bottom of the stove and be made fast to the latter at that point. The arrangement is equivalent to a 'portable furnace,' such as is usually placed in a cellar or a basement hall.

"In Fig. 207 a stove is represented standing close to an open window. The movable semi-cylinder of metal, commonly used for a screen, has been so placed as to inclose the stove on all sides, except that toward the windows. Cold air may then be freely admitted; it is

quickly warmed by contact with the stove and is thrown upward with the general current.

"Figure 208 shows air brought in so as to be warmed by contact with a stovepipe. The inlet flue is enlarged and runs up with the stovepipe like a jacket for same distance.

"Figure 209 shows how a stovepipe may assist in removing injurious air. The diagram represents a two-story house with a chimney which comes down to only a very short distance from the roof. The opening into the chimney for the stovepipe is enlarged so as to receive a much larger pipe, which encircles the stovepipe like a jacket. This jacket may stop short at *A*, or may be carried through the floor to *B*, in the first story. It will secure a draught from either story as may be arranged. The idea of this and the preceding figure is borrowed from an article in the report of the Michigan Board of Health for 1879."

I do not propose, however, to describe the thousand-and-one contrivances which may be used to secure the entrance and exit of air in such houses as those now under consideration. Each house is, to a certain extent, a problem by itself, but it is a very simple problem, which any moderately ingenious tinner or sheet-iron worker will have no difficulty in solving, if he will only master the few simple laws of the movement of air, which have been given in previous chapters.

Every stove-dealer should possess this knowledge in order to deal understandingly with the complaints which will be made to him about bad draught, etc., etc., complaints which are almost always due, not to the stove, but to improper construction or location of flues.

CHAPTER XX.

VENTILATION OF TUNNELS. RAILWAY CARS. SHIPS. PRISONS. SHOPS. STABLES. SEWERS. COOLING OF AIR. CONCLUSION.

THE principles involved in the ventilation of tunnels while in process of construction do not differ materially from those involved in driving mine galleries. Where drills worked by compressed air are used, as is now commonly the case, the escaping air produces a fair condition of the atmosphere at the face of the headings while the drills are actually at work, but additional means of mechanical ventilation are necessary in long tunnels to get rid of the smoke and gases produced by explosions, and to enable the masons and others employed in the shaft to obtain the requisite amount of fresh air.

In the construction of the Mont Cenis and the St. Gothard tunnels an aspirating apparatus, having a capacity of about 25,000 cubic feet per minute was employed, but it did not succeed in ventilating the center of the tunnels, and there was much sickness among the workmen, especially among those employed in the St. Gothard tunnel.

In the construction of the new Croton Aqueduct tunnel blowers were employed, from which the air was taken in spiral riveted sheet-iron pipes to a point about 300 feet back of the heading. It is best to arrange such a system so that the action of the blower can be reversed so as to exhaust for a short time after blasting, and thus to remove a large part of the smoke and gases before they diffuse into the tunnel. The pipes should be at least 12 inches in diameter. If aspiration is to be employed for ventilating the tunnel itself it is necessary that a fresh-air supply be provided, either through a separate inlet or by dividing the passage by a partition or brattice.

Attempts to produce currents by means of compressed air jets gave very poor results in the Croton tunnel.

The ventilation of railway tunnels after they have been constructed presents special difficulties which depend mainly on the frequency of the passage of trains through them. In the long tunnels of

the St. Gothard and the Mont Cenis the passage of trains is comparatively infrequent, and the difference in temperature between the interior of the tunnel and the outer air combined with the piston-like action of the train itself has been found sufficient to produce the necessary change of air. In *Engineering*, April 21, 1871, page 286, Mr. Ramsbottom describes the mechanical ventilation of the Liverpool tunnel on the London and Northwestern Railway. This tunnel is over a mile in length, and has a mean sectional area of 430 square feet. The ventilation is effected by a fan 29 feet 4 inches in external diameter, and 7 feet 6 inches wide, which is placed in a shaft 175 feet high and 23 feet in diameter at the top, rising from near the center of the tunnel. With a speed of 45 revolutions per minute the fan cleared the tunnel of smoke and steam in about eight minutes, discharging about 431,000 cubic feet of air per minute.

In a valuable paper on tunnel ventilation, read before the American Society of Civil Engineers in December, 1890, Mr. N. W. Eayrs describes the ventilation of the Hoosac tunnel and the St. Louis tunnel. The Hoosac tunnel is about 4¾ miles long, perfectly straight, and is ventilated by an elliptical central shaft 27x15 feet in diameter and 1,000 feet high above the top of the tunnel, which is 24 feet wide and 22 feet high. The velocity of the air is sufficient to clear it of smoke in about 15 minutes after the passage of a train. In winter the direction of the current is from the portals to and up the central shaft; in summer it is the reverse.

The St. Louis tunnel is 4,095 feet long, and is ventilated by a fan 15 feet in diameter and 9 feet wide placed near the center of the tunnel. At 110 revolutions per minute the tunnel is cleared of smoke in from four to five minutes. The results have been fairly satisfactory, but Mr. Eayrs predicts that more efficient means of ventilation must be provided as traffic increases, and refers to the Mersey tunnel at Liverpool as being the best example of successful ventilation with heavy traffic. This tunnel is 4,960 feet long, under the river, and is 26 feet wide; it is double-tracked throughout. The grade in a portion of the tunnel is 196 feet to the mile. The principle on which the ventilation was planned was to admit fresh air at the stations, and draw it either way to points midway between stations, where the ventilating fans were placed. An auxiliary tunnel or air drift, 7 feet 2 inches in diameter, runs parallel with the main tunnel, and is connected with it and the stations by sliding doors, so that air can be drawn from any point desired. The fans are four in number, two 40 feet diameter and 12 feet wide, and two 30 feet diameter and 10 feet

wide. Their collective capacity is 500,000 feet per minute; average number of revolutions per minute is 45.

For purposes of ventilation the tunnel is divided into four sections, one fan being allotted to each; but by means of the doors in the air passages the fans can be made to do each other's work, and no complete stoppage of ventilation is possible. The 30-foot fan at Liverpool ventilates the James Street station and the section of the tunnel between that station and the terminus. The capacity of this fan is about 120,000 cubic feet per minute. The 40-foot fan at Liverpool ventilates the section of the tunnel between James Street station and the center of the river. Capacity about 130,000 cubic feet per minute. The 40-foot fan at Shore Road, Birkenhead, ventilates the section between the middle of the river and the Hamilton Square station, and has a capacity of 130,000 cubic feet per minute. The 30-foot fan, the fourth in the series, is located at Hamilton Street, nearly midway between Hamilton Square station and Borough Road, and has a capacity of about 120,000 cubic feet. The combined fans have a capacity about one-seventh that of the entire tunnel. These fans are all built on the lines of the well-known Guibal fan. About 300 trains a day pass through the tunnel, giving a maximum train service of one train each way every five minutes. With this heavy traffic, and with the severe grades, the ventilation of both tunnel and stations is excellent.

Several schemes have been proposed for getting rid of the offensive fumes and gases thrown off by coal-burning locomotives in passing through such tunnels as those of the underground railway in London, the Fourth Avenue tunnel in New York, the Baltimore tunnels, etc. One is that of Dr. Richard Neale to absorb the sulphur fumes and carbonic acid by means of trays of lime or screens kept wet with alkaline solutions, forming what he calls a chemical lung. Another is to cut off the upper part of the tunnel by a horizontal partition having a slit in it for the passage of the top of the locomotive smoke-stack, and to discharge all the smoke, etc., into this upper flue, from which it is to be drawn by an exhaust fan. This has been patented. Another plan is that of Mr. Anderson, in which a cast-iron duct with valves 16 feet apart is laid between the rails and receives the smoke and gases from the locomotive. The valves are opened by a slide suspended from the locomotive in such a way that before one valve closes a second one is opened. The true solution will probably be the use of motors which do not produce smoke and gases.

In a series of determinations of the proportion of carbonic acid in the air of passenger and smoking cars made by Prof. William R.

Nichols, and published in the Sixth Report of the Massachusetts State Board of Health, 1875, the amount was found to be from 14 to 36 parts per 10,000. Probably the worst air ever tested was that in an American railway car running between St. Petersburgh and Moscow in the winter of 1866. This car was 50 feet long and carried 80 third-class passengers, the outside temperature was 22° F. below zero and the only means of heating the car were the bodies of the inmates. In nine hours the temperature in the upper part of the car was 21° F. and at the floor was 6° F. below zero, while the carbonic acid had increased from 14 per 10,000 at starting to 94 per 10,000.

Another series of carbonic acid tests made by Professor Howard is given in the Report on the Sanitary Inspection of Passenger Coaches by Dr. R. Harvey Reed, published in 1888, the figures ranging from 4.4 per 10,000 in July, when all doors and windows were probably open, to 14.26 per 10,000 in December. All the figures in this series are low—so low in fact as to make it probable that some source of error existed in the analyses.

Many inventors have busied themselves with the problem of ventilating railway cars, and many patents have been granted for appliances for this purpose, but thus far the difficulties have not been overcome. The problem is to provide an apparatus which will change the air in a passenger coach at least once in five minutes, which will do this while the car is standing still as well as while it is in motion, and which will exclude dust. This cannot be done if the windows of the car are under the control of the passengers, and it cannot be done by any openings into the car, whether at top, bottom or sides, without the application of mechanical power. A combination of fans run by electromotors, with steam pipes passing in metal-lined ducts placed at the angle formed by the sides and floor of the cars, the fresh air to enter around these pipes through dust-filtering screens, and the fans to draw off air from above, would seem to be indicated in this case. The supply of air should be not less than 900 cubic feet of air per head per hour, and the ducts, fans, etc., should be of such size that in warm weather this amount could easily be doubled without opening doors or windows.

SHIPS.

Some of the earlier attempts to improve upon the old-fashioned, and still usual, method of ventilating ships by means of windsails are referred to in Chapter II. of this work. Since the time of Sutton, about 100 patents have been granted for methods of ship ventilation, but none of these have met with general acceptance, and for sailing

vessels and freight steamers the windsail is still almost the only appliance used. In modern ships of war and in large passenger steamers of recent construction fans are used and give good results, but they are always supplemented by large cylindrical vertical pipes projecting above the deck, with movable cowls having trumpet-shaped mouths, which can be turned so as to either face the wind or away from it. In a few ships a form of air pump has been tried which is worked by the rolling of the vessel, but the effect is small, being less than 2,500 cubic feet of air per hour. On the berth deck of a warship constructed 20 years ago each man will have less than 120 cubic feet of air space, one watch being on deck, and with all openings in port the proportion of carbonic acid may rise to from 15 to 34 parts in 10,000. Upon the best-arranged and best-ventilated of the new passenger steamships on the New York and Liverpool lines, which have fan ventilation and many wind tubes, the air in the staterooms of the first-cabin passengers is usually nearly free from odor, the proportion of carbonic acid present being probably about 8 per 10,000.

The idea of obtaining motive power for the air by the use of the galley or furnace fires of the ship, as was proposed by Sutton, has been often tried but with only partial success, chiefly because the pipes used were entirely too small. But on the fast North Atlantic steamers the furnace fires cannot be used to aspire air to feed them from remote parts of the ship, because they must have the largest possible supply of air, free from friction to enable them to do their work, and hence are put in almost direct connection with the outer air by large hatchways.

On some of our most recently-constructed steel cruisers the fresh-air supply is ordinarily obtained through hatchways and ventilating tubes with movable cowls and the foul air is drawn out through special ducts connected with Sturtevant blowers. On the cruiser "Baltimore" the cubic air space per man on the forward berth deck is 142.3 cubic feet for 247 men. There are two exhaust blowers, each 5 feet 6 inches in diameter, with a capacity of 10,000 cubic feet per minute and connected with a main air duct 23 inches in diameter. From this main duct smaller ducts pass to nearly all parts of the ship except the boiler space. From the berth deck above referred to there are 14 of these exhaust ducts, each 4 inches in diameter and opening near the ceiling. There is no heating apparatus for this deck. On the cruiser "San Francisco" the plan is essentially the same; the berth deck gives 121.2 cubic feet of air space to each of 302 men, the blowers are 5 feet in diameter and the main air duct is 27x15 inches.

On the gunboat "Yorktown," the berth deck gives 76 cubic feet of air space to each of 87 men, and the two exhaust blowers discharge into the fireroom, the main ducts being 14 inches in diameter. In all these ships the fans can be reversed so as to blow air in instead of drawing it out, it being the intention to use this method in very rough weather, or for the purpose of driving sulphurous acid fumes through the ship for purposes of disinfection if required. For the above data I am indebted to the courtesy of Capt. T. D. Wilson, Chief of the Bureau of Construction of the Navy.

Medical Inspector W. K. Van Reypen, U. S. Navy, informs me that on the "San Francisco," when the blowers are running at 400 revolutions, the berth deck, storerooms, sick bay and officers' quarters are well ventilated, but that the engine and firerooms are excessively hot, and are only ventilated by funnels and windsails. The compartment for the dynamo and steam-steering apparatus is almost uninhabitable on account of the heat, and Dr. Van Reypen recommends that a separate blower be provided of sufficient capacity and power to thoroughly ventilate the engine-room, fireroom and dynamo compartment.

As regards the "Yorktown," Surgeon George E. H. Harmon, U. S. Navy, states that the ventilation of the forward part of the ship is fairly well effected, but that that of the after part is not satisfactory. The delivery of the foul air into the firerooms interferes with the downward cool air current through the cowled ventilators from the open air above, and thus raises the temperature and adds materially to the suffering of the firemen.

The pipes leading from the wardroom and officers' rooms in the after part of the ship open into a large space between decks. One of these decks is not air tight and has several hatches, the result being that the aspiration from the officers' quarters is very small. In this ship the dynamo room is ventilated by a special blower, and the result is good.

In warships of the monitor type constant mechanical ventilation is of course a necessity. On the "Miantonomoh" the principal berth deck may be fairly ventilated at all times, but the turret chambers, which are occupied by hammocks at night, have no provisions for change of air. The indraught registers on the berth deck are flush with the deck and admit an undue amount of dust from the sweepings, etc., into the flues, the interior of which is practically inaccessible.

A simple and compact arrangement of a blowing fan combined with radiators and automatic regulation of temperature has been

placed on some of the New York ferryboats on the East River and produces very good results. Heating is in this case more important than ventilation.

The British steamship "Ophir," of the Oriental line to Australia, is ventilated by means of jets of compressed air which are used to induce movement of the air surrounding the jets. This does not appear to be an economical way of applying power to effect the movement of air, but it has the advantage in hot climates of cooling it somewhat if water is used to convey away the heat generated in the compression chambers.

The rules for the ventilation of transports issued by the Sanitary Commission of Bombay in 1866 direct that the space between decks occupied by troops shall be kept free of partitions, and that an air-shaft at least 2½ feet square shall be placed at each end of this space, having its lower end flush with the ceiling. Four metal tubes, each 18 inches in diameter, with movable cowls to face the wind are to be inserted, two on each side, one about one-fourth of the length of the deck from the foremost end, the other the same distance from the after end. At 9 inches below the bottom of each tube is to be fixed a horizontal screen to deflect the air along the ceiling. Apparently this is to provide for the needs of four or five hundred men, and it might give each man 15 cubic feet of air per minute with a good wind.

The most complete published report upon the ventilation of a modern warship that I have seen is that by J. Gärtner upon the iron corvette "Sachsen" in the Deutsche Vierteljahrsschrift f. öffentl. Gsndhtspflege, Vol. 13, 1881, page 309. This gives data as to the temperature, moisture and carbonic impurity of the air at different points, the direction of currents, etc. Mechanical ventilation for certain parts of the ship was provided by blowers, and when these were acting the carbonic impurity was from 10 to 20 per 10,000. In some parts of the ship the amount of carbonic acid was so great that lamps burned dimly and respiration was affected. In a general way it may be said that the air was as impure as it is in a crowded theater, yet there was comparatively little sickness. Under some circumstances the ventilation of the hold of a ship should be restricted to fine weather in order to prevent the damage to certain articles of cargo which may be produced by admitting to them air loaded with moisture.

PRISONS.

If the objects in view in the construction of a prison are merely the safe keeping of the prisoners and the prevention of palpable and

evident filth, without attempting to furnish better ventilation or more healthful surroundings than are to be found in the bedroom of the average laborer or than they are accustomed to in the dens and slums from which most of them come, if, in other words, it is intended that no special effort shall be made to preserve and improve the health of the convicts, but that they shall be left to the natural processes of extermination of the unfittest, then the majority of our prisons will meet these requirements so far as ventilation is concerned.

Municipal station houses and jails intended for the temporary detention of prisoners are usually heated by direct radiation and have little or no provision for fresh-air supply in cold weather. In the larger penitentiaries, for long-time detention of convicts, there are usually a few fresh-air openings, quite insufficient to secure the desired amount, and some of the cells are much more heated than others. The defective ventilation in penitentiaries is one reason why the death rate from consumption is so great in them, another reason being that the criminal class is especially liable to this disease, so that the proportion of persons who are affected with tuberculosis when they enter prison is about twice as great as is found in other people of the same age.

There are wide differences of opinion among wardens and other officials of prisons as to how such buildings should be constructed, whether the cells should have brick, stone or iron walls, how many tiers of cells are best, whether central or lateral corridors are to be preferred, and whether solitary confinement should be the rule or the exception, but all of them, or nearly all, declare that one of the chief objects of the penitentiary is the reformation of the prisoner, and that this cannot be accomplished unless he is kept in good health and is given plenty of fresh air.

If this is to be done each man should receive at least 2,500 cubic feet of fresh air per hour. The openings for exit and entrance of air should be beyond the control of the prisoner, and the temperature should not vary more than 3 degrees in different cells.

There are two essentially different plans of prison construction in use. In the first, known as the Pentonville or the Auburn system, the cells are arranged in blocks of several tiers in height, and this block is surrounded by an outer building, between the walls of which and the doors of the tiers of cells in each side is an open corridor, not divided by floors corresponding to the floors of the several tiers, the area of this hall being unobstructed from the floor of the first story to ceiling of upper story, as shown in Fig. 210, which is a cross-section of one of the cell blocks in the New York State Reformatory at Elmira.

The heaters are round, vertical tube radiators set under the windows, with openings in the center of the bases. In corresponding openings in the stone flags are set strong cast-iron pipes, with flanges built into the masonry. These pipes extend up through the openings in the bases of the radiators which they fit closely, connecting the fresh-air ducts with the radiators and preventing water (when washing the floors) from entering the ducts.

The number of concentric rows of tubes in the radiators is four. The two outer rows are separated from the inner ones by a galvanized

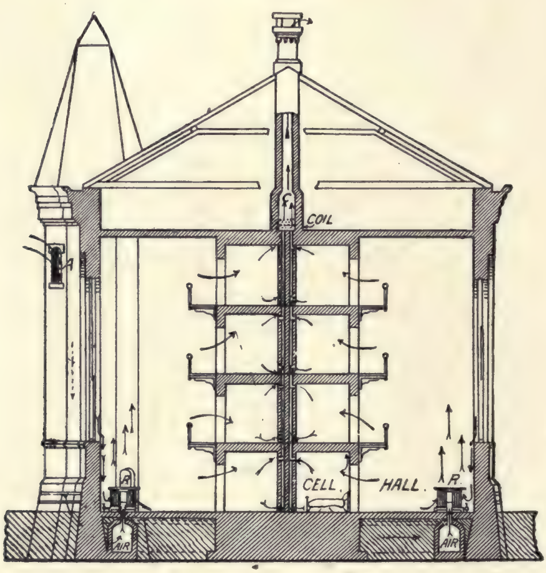


FIG. 210.

sheet-iron partition, the object being to divide the inside rows from the outer ones so as to make part of each radiator practically an indirect heater, the air from the duct only coming in contact with the inner rows, while the outer rows warm the air already within the halls and give direct radiation.

There are 500 cells, each of which have two 4x4-inch flues, one from near the ceiling and the other from a cast-iron niche near the floor. The one near the ceiling is fitted with a heavy cast-iron frame built into the walls, while the lower one connects with the top of the

"night-bucket" niche. The flues are separate their whole length, each terminating in the exhaust chamber *c* as shown, and there are no means of closing them.

The exhaust chambers extend the whole length of the blocks of cells, so that the flues are perfectly straight, a person in the chamber being able to see the light in the cells.

The steam coils within the exhaust chambers are 1¼-inch pipes and extend over the upper ends of all the flues.

The air ducts extend all around the wings near the outer walls as shown, and communicate with the fresh-air shafts or towers, each tower having a separate section of duct.

The course of the fresh air is in at the window *a* and down through the tower, thence through the air ducts to the radiators, through which it passes to the halls, from which it is drawn into the cells by the action of the independent flues, thence out through the aspirator.

The coils in the aspirator or exhaust chamber are not connected with the regular heating system of steam pipes, but with a special system provided for them, with the valves in the boiler room, so that they can be under the control of the engineer without his entering the buildings, and also to admit of using the exhaust chamber and coils during the summer and when steam is not otherwise required, which is done, causing a rapid movement at all seasons.*

In a system of this kind the upper tier of cells must be overheated if the lower tier is to be kept comfortable in cold weather, and the greater the number of tiers the greater the difficulty in this respect. On this plan there should not be more than two tiers of cells.

A much better plan is to separate each double row of cells by a passageway from 4 to 6 feet wide, as is done in the Rhode Island State Prison. In this passageway can be carried the heating and ventilating apparatus. In the Rhode Island Prison there are three tiers of cells, and the halls containing them are heated by direct-indirect radiation. Each cell has a 5-inch foul-air flue extending from near its floor to the roof where it is capped with a cowl. For reasons given on page 275 so many separate upcast flues are undesirable, unless each cell has an independent air supply.

A modification of this plan is that patented by Mr. Charles E. Felton, and used in the House of Correction at Chicago. In this the heating apparatus and fresh-air flues are also in the central passage, and are so arranged that each cell has its own heating surface and

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* From *The Sanitary Engineer*, April 26, 1883.

fresh-air supply in the rear wall of the cell. In a system of this kind it is best that the fresh-air entrance be near the ceiling and the foul-air outlet near the floor. To ensure constant movement of the air all the foul-air ducts should unite into one which should be connected with an aspirating chimney or with an aspirating fan. If, however, the solitary confinement plan is to be really carried out, this uniting of ducts may furnish a means of communication between prisoners which is not desirable, unless special arrangements are made to prevent this.

The other type of prison construction is that in which the cells are arranged in tiers on each side of a central hall, the outer walls of the cells being formed by the outer wall of the building. This is the plan of the Eastern Penitentiary in Philadelphia, in which the heating of the cells is partly by the admission of warm air from the central hall, but mainly by a single line of steam pipe which passes around the base of the cell near the floor. The result is great variation in temperature in the different cells, ranging from 70° to 82° F. in one block. Each cell has a small opening from 2 to 4 inches in diameter near the floor in the outer wall for the admission of fresh air, but this is invariably plugged up in some way by the prisoner in cold weather. The foul-air outlet is in the ceiling, and is also often closed. No aspirating force is employed. The result is that the air in a cell is often very impure, the carbonic impurity added having been found to be from 4 to 9.5 parts in 10,000, and this has, no doubt, been one cause of the high death rate from consumption in this prison.

In the Lackawanna Prison, described and figured in *The Engineering Record* of March 2, 1889, the cells are also on each side of a central corridor, but the heating is by indirect radiation, the registers being cast in the sill of the iron door frames of the cells. The foul-air flues in the outer walls open near the floor and connect above with ducts leading to an aspiration shaft.

SHOPS, ETC.

The ventilation of workshops, factories, mills, etc., is, as a rule, not a difficult matter, although it is rarely attended to. Power is usually available for some form of mechanical ventilation. An example of a good system of ventilation by means of an aspirating chimney is given by L. Perreau, who arranged it for a weaving shed 201x108 feet and 11 feet high, in which 400 persons were employed. About 1,500 cubic feet of air per head per hour is supplied which enters by 128 openings at the roof, and the foul air is drawn off through openings in the floor into ducts leading to the factory chimney,

which is 49.4 square feet in sectional area and 177 feet high, and the temperature in which is over 400° F. when the five steam boilers connected with it are at work. The shed is heated by overhead pipes, and the fresh air is drawn down over these by the aspirating chimney.*

In some shops, as in paper mills, a great volume of steam is produced which should be removed promptly. For this purpose a heated hood or diaphragm placed above the dryers has been found to work well, producing an upward current. An exhaust fan connected with the hood and forcing the steam through thin metal pipes of 8 and 10 inches diameter, in which it would condense, would be an economical method of dealing with such vapors, as the heat evolved in condensation and the hot water produced could both be used to warm the room. In workshops, as in most other rooms, the ventilation problem is how to get enough fresh air in at the proper points, for if this be done there is little difficulty in disposing of the foul air.

It is the neglect of this point that often produces trouble in large store or warehouses in which at times there are stored quantites of substances liable to produce unpleasant odors—as, for instance, a large quantity of sweating grain. Ventilation will not be produced by merely making a hole in the roof—not even if an exhaust fan is placed in the hole. There must be air inlets so placed that the currents from them to the outlets will change the air of the room.

STABLES.

For all temperatures above 32° F. the amount of air supply for horses, oxen and sheep should be unlimited, to obtain the best results. Where it must be limited, it should be, for a horse, from 4,000 to 6,000 cubic feet of fresh air per hour.

In the model plan of a stable proposed by the English Barracks and Hospital Improvement Commission in 1863, 100 square feet of floor space and 1,605 cubic feet of air space were allowed to each horse. Fresh-air inlets giving 1 square foot of area per horse were provided at the eaves by means of air bricks or Sheringham valves, and to ensure a fresh-air supply near the head of the horse when he is lying down, an air brick, low down, is placed between every two stalls. The outlet is by a louver at the edge giving 4 square feet outlet to each horse.

For cavalry stables in the English climate this would, no doubt answer well, but in cold and windy weather the currents produced through the lower openings would at times be dangerous.

* See Compte Rendu de la Soc. des Ingénieurs Civils, August, 1890, 293.

According to Dr. F. Smith*, a horse inhales about 45 cubic feet of air per hour and gives off between 6 and 7 cubic feet of carbonic acid in the same time. He accepts for stables the same ratio of permissible carbonic impurity as that fixed by Parkes and De Chaumont for barrack rooms—namely, 2 parts in 10,000, and using De Chaumont's formula of $\frac{e}{p} = d$, where $e =$ the number of cubic feet of CO_2 exhaled per hour—viz., $6.^5$; $p =$ the limit of carbonic impurity per cubic foot of air permissible—viz., .0002; and $d =$ the number of cubic feet of fresh air per horse required, the result is $\frac{6.^5}{.0002} = 32,500$ cubic feet of air per hour. In the last edition of Parkes' "Hygiene" (page 187) e is given as $1.^{13}$, which would make the air supply required 5,650 cubic feet per hour, and this is more nearly correct. In stables built of brick and of what is ordinarily called good construction, the arrangements for air supply, when they are provided at all, usually are for a much smaller supply than this. No doubt, horses and cattle can endure a smaller supply of fresh air in proportion to their weight than man without great risks of producing disease; even so low an allowance as 500 cubic feet per hour per horse in a large car stable has not produced evident bad results, but in this case the stable afforded each horse 1,200 cubic feet of air space, half the horses were out the greater part of the time, and much change of air went on through open doors, etc., besides that specially provided for by the ventilating tubes. The most extended series of examinations of air of stables which I have met with is contained in a work by Prof. Max Märker, a translation of which, by Professor Leyder, under the title of "Recherches sur la Ventilation Naturelle et la Ventilation Artificielle principalement dans les ètables," was published in Paris in 1873. Professor Märker found the proportion of carbonic acid in some stables in which the health of the animals seemed good to be from 30 to 40 parts per 10,000, or three or four times as great as that fixed by Pettenkofer as the permissible limit of impurity for human habitations.

Of late years architects have been called on for plans of some elaborate and costly stable buildings intended for fine horses, and in these there are required special arrangements for warming and ventilation. Thus in Mr. Work's stable, described in *The Sanitary Engineer* of November 8, 1883, the air supply for 10 horses is furnished through a direct-indirect radiator having 4 square feet of opening, and outlets into special flues are provided near the ceiling. The ducts

* "Manual of Veterinary Hygiene," Lond., 1887.

are too small for a proper supply for 10 horses, and it would have been better to have made outlets for the foul air, both above and near the floor, into special vertical flues.

A better arrangement is that in Mr. Pickhardt's stable, described and illustrated in *The Sanitary Engineer* of July 26, 1883. In this building the fresh air is brought in through indirect radiators and discharged into the room through four registers, one in each corner, about 8 feet above the floor. The outlets are about 1 foot above the floor and open into flues 1 foot square which extend 6 or 7 feet above the room and have each at least 9 square feet of surface of accelerating steam coil.

In planning the ventilation of a stable that is to be well built, and not to rely on cracks, open doors, etc., for fresh air, flues, registers, etc., a supply of 6,000 cubic feet of air per hour per horse should be provided for, and the heating surface should be proportioned to heat this amount of air from zero to 60° F. It is easy to diminish the air supply or the heat, or both, to suit circumstances, and the proper apparatus will cost very little more than one adapted to half the above estimate.

SEWERS AND HOUSE DRAINS.

All sewers and soil pipes should be provided with the means of securing an abundant and nearly constant supply of fresh air in order to promote the growth of the aerobic micro-organisms, which are the chief agents in decomposing the organic matters contained in them, and to dilute and remove the offensive or noxious gases which may be developed in them. If the sewers are properly planned and constructed, with smooth inverts of uniformly sufficient downward grade toward the outlet, and with a sufficient supply of water—while only fresh sewage is admitted to them—their ventilation is a comparatively easy matter. The tendency to the production of foul gases in such sewers is small; and if openings to the outer air are provided at intervals, care being taken that such an opening is placed at every dead end, a constant movement of air will be secured through the influence of winds, of the differences in temperature and moisture between the sewer air and the free atmosphere, and of the movement of the current of sewage.

Under such circumstances, the precise direction of the current matters little, and it is unnecessary to provide shafts with cowls or furnaces to induce a current in a particular direction.

It has often been proposed to ventilate sewers by means of large tall shafts or chimneys specially constructed for the purpose—or through the chimneys and furnaces of large factories—and the ex-

periment has been tried, but the influence of such shafts extends only to the nearest inlet; and if this be two or three hundred yards away, the influence is small, owing to the immense quantities of soil air which stream in through the walls of ordinary brick sewers. Where the sewers and house drains are under the control of the municipal engineers, and are properly constructed and managed, and the houses on a given street are nearly uniform in height, excellent sewer ventilation may be secured by omitting all traps in the house drains, carrying the soil pipe up with a free opening at its top above the roof, and thus allowing the house pipes to ventilate the sewer.

But where the sewers are badly constructed—so that accumulations of decomposing filth occur at certain points—where cesspool overflows are admitted to them, and where the houses vary much in height, so that the top of the soil pipe of one house may be beneath the level of the windows of living rooms in another, it is not expedient to use the soil pipes as ventilators, and it is better to prevent this by placing a trap on the main drain between the house and the sewer. When this is done the usual plan is to provide air inlets and outlets to the sewer by means of openings at the street level, placed at intervals of three or four hundred feet and covered with gratings; while a separate ventilation is provided for the soil pipe by means of a fresh-air inlet placed on the house side of the trap.

Occasionally there is a demand for some means of cooling the fresh-air supply in warm weather, as in legislative assembly halls, in summer theaters, or for the room of a sick person, and in the description of the ventilating appliances of some buildings it is stated that provision is made for doing this by blowing the air over ice placed on racks, etc. The use of ice for this purpose is a very expensive method. It was tried in the room in the White House occupied by President Garfield, in July and August, 1881, during his illness, and with a 36-inch blower, forcing about 22,000 cubic feet of air per hour over ice into the room, the temperature was lowered 5.4° F., when the outside temperature was 84.9° F., and about 436 pounds of ice were melted per hour. The description of the apparatus, and of the results obtained, is given in a pamphlet entitled "Reports of Officers of the Navy on Ventilating and Cooling the Executive Mansion during the Illness of President Garfield," 8vo., Washington, Government Printing Office, 1882, which will be found interesting by those who wish to provide such an apparatus in an emergency.

If a permanent plant for this purpose be desired, some form of compressed air apparatus in which the heat evolved by the compres-

sion of the air is removed by cold-water pipes, and the desired coolness is produced by the expansion of the air will probably be found to be the most satisfactory and economical. It should be remembered, however, that when the air of an assembly room is loaded with moisture the introduction of cold air may precipitate this moisture and produce a fog or cloud if there is dust in the air. This was actually the result of one experiment of blowing cold air into one of the assembly halls at the Capitol in Washington. It should also be remembered that there is danger to health in cooling the air 8 or 10 degrees below that of the outer air. A plentiful supply of air is usually the best method to secure relief from the feeling of excessive heat.

In conclusion, a few words about making contracts for heating and ventilating apparatus, and about the means for securing proper ventilation for public buildings, may not be out of place. The usual mode of obtaining bids and making contracts for heating and ventilating apparatus is not a good one, and it is not surprising that it often produces unsatisfactory results. Contractors for heating and ventilating apparatus are invited, or are permitted to make their own specifications and state what they will do the work for, the only thing required by the architect or builder being that "the building shall be heated by steam to a temperature of 70° F. in the coldest weather," to which may be added that, "satisfactory ventilation must be provided." The work is then given to the lowest bidder, little or no consideration being given to the relative merits of the different schemes. Even if the schemes are compared, there is no security that the one who furnishes the best plan, with sufficient details to judge of its merits, will get the contract. His figures may be used merely to fix a price for the work, or the information he gives may be used to prepare specifications for another and lower bidder. Competition under such circumstances is a farce. The firms which employ a competent engineer and can be relied on for good work have learned by experience that it is useless to employ an expert to make plans and estimates which are to be judged by persons who know nothing about the matter, and who will simply look at the item of cost.

The firms which are specially interested in some particular kind of heating apparatus, propelling or exhaust fan, or patent system, often have a blank form of specification, which they can fill in in half an hour, on the "cubic space to be heated" principle, and, of course, they are always ready to compete at the shortest notice. But the best plan will rarely, if ever, be the cheapest one ; in fact, it is a good rule to exclude at once the lowest bids to the extent of

one-fourth of the total number of bids. What is wanted is to get the best, or, at all events, thoroughly good, work at a fair price. The essential thing to secure this is a detailed specification with plans, showing for each room the position and size of flues and registers, and of such direct or direct-indirect radiators as may be desired, and the quantity of air to be introduced and removed per hour, and also showing the location, size, and material of boilers or heaters, the size and location of mains, and the size and location of indirect heaters, coils or radiating surfaces. If the architect wishes to employ a hot-blast system, or to have plans for such a system to compete with the usual methods, he should specify the position and size of flues and registers for each room, and the ordinary and maximum velocity at which the air is to pass through each register, and also require that means be supplied for regulating the temperature of the air in each room without interfering with the quantity delivered, and then call upon firms doing this class of work to submit plans showing how they propose to meet these requirements. In comparing bids on such plans with those on plans for divided radiating surfaces, whether the motive power be supplied by aspirating flues or chimneys, with or without accelerating steam coils, or by propelling or aspirating fans, he should consider with care the expense of running the different forms of apparatus, including the salary of an engineer, etc., and also what is to be done to supply heat in case the blowing apparatus must be stopped for repairs in cold weather. This is especially important in a building permanently occupied, such as a hospital. He should also remember that if a patented apparatus, or one that necessitates the employment of a particular piece of apparatus made only by one firm, is accepted, there will be no possibility of competition when repairs or additions become necessary, and that five or ten years hence it may be very difficult to obtain the peculiar appliances needed for such repairs or additions. I do not mean by this that he should not specify for particular patented pieces of apparatus, such as valves, etc., but that he should be very wary about accepting any so-called "system of ventilation" which is controlled by a single firm.

A properly drawn specification or contract will give the number of square feet of radiating surface to be furnished. Contractors know that architects very rarely make examinations or measurements as to the amount of heating surface actually furnished, and hence unscrupulous men do not hesitate to bid low and reduce the quantity. Moreover, as has been pointed out in the chapter on radiators, the actual amount of heating surface in most patented or proprietary cast-iron

radiators is from 20 to 30 per cent. less than that which is claimed for them.

The architect should assure himself by evidence other than that of the contractor, if he cannot make the examinations and measurements himself, that the amount of heating surface contracted for has actually been furnished.

In the chapter on schools allusion has been made to the Massachusetts law to secure proper ventilation and sanitary arrangements of public buildings. The idea of effecting this by a central State authority is a good one, for it will certainly not be done by local authorities ; but it is hardly to be expected that police inspectors will be able to exercise satisfactory supervision over these matters. It requires the constant service of a competent heating engineer, to whom all plans for the heating and ventilation of the schools, asylums, prisons and other buildings constructed and maintained at public expense, whether State or municipal, should be submitted for approval. Such an engineer should be connected with the State Board of Health, which is the proper department to have charge of matters of this kind, and he should not be connected in any way with any heating firm or with any patent or proprietary apparatus or schemes.

Finally.—I wish to call special attention to the fact that any system of combined heating and ventilating apparatus requires constant care as to its cleanliness, preservation and adjustment to the requirements of the inmates, which requirements vary with the season, the direction and force of the wind, and sometimes with the hour of the day, if the best results which the apparatus is capable of are to be obtained.

The most wasteful of all expenditures for a public building is to provide an elaborate and costly apparatus for heating and ventilation, and then intrust it to the care of an ignorant and careless engineer, selected not on account of his knowledge of what is to be done and how to do it, but because he is "somebody's nephew," or is an "active politician," or is "unable to support his family."

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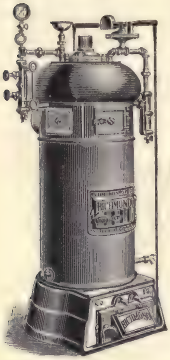

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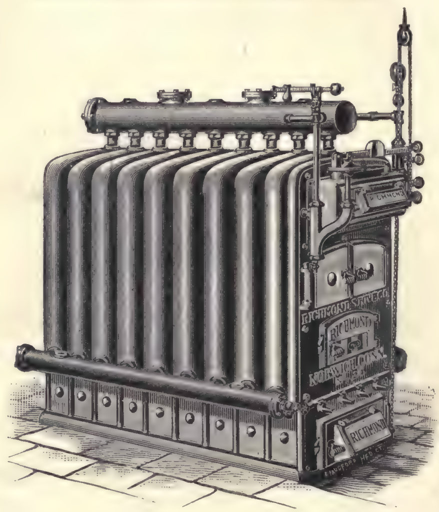

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